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To: Dr. D. Mills
Director of Research

SHORT-TERM INFLOW FORECAST MODEL FOR THE MISSISSAGI RIVER

Report No. 91-18-K

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ABSTRACT

This investigation was carried out in response to a request by the Operations Planning Facilities Department of PSOD. The main goal of the study was to develop a tool capable of forecasting the local inflows 1 to 4 days in advance, in the Mississagi River basin. Two types of models, namely conceptual and stochastic, were selected as potential predicting tools. Three models were developed for PC applications. A model is considered acceptable if the forecasted daily inflows over a given period of time exceed the accuracy of 0.7, 0.5, 0.3 and 0.1 in terms of the Nash Coefficients (CNA) for 1, 2, 3 and 4 days in advance, respectively. All three models described in the report satisfy these requirements for almost all flood events during the four-year (1975 - 1979) period selected for testing the accuracy of the models.

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P.A. Zielinski

1. INTRODUCTION

Ontario Hydro owns and operates one storage dam and four hydraulic generating stations in the Mississagi River basin. Any substantial improvement of the effectiveness and reliability of the operation of these facilities requires accurate short-term forecasts of river flows. At the request of the Operations Planning Facilities Department, an investigation was carried out to develop forecasting tools capable of forecasting the local inflows, 1 to 4 days in advance, in one or more sub-basins of the Mississagi River.

This report presents the results of the developmental works carried out by the Probability and Reliability Unit of the Operations Research on forecasting models. These models are developed for PC applications. The performance criterion of the forecasting models is defined in terms of the Nash Coefficient (CNA). A model is considered acceptable if the CNA of the forecasted daily inflows over a given period of time is not less than 0.7, 0.5, 0.3 and 0.1 for 1, 2, 3 and 4 days ahead, respectively.

Section 2 of the report presents a description of the study area and the data used for calibration and validation purposes. Sections 3 and 4 describe the models that were developed and used in the study. Results and discussion are presented in Section 5. Section 6 presents the conclusions of the study.

2. STUDY AREA AND DATA AVAILABLE

The Mississagi River basin (see/8/)is located in the District of Algoma with the northern portion extending into the District of Sudbury (Figure 1). It drains an area of 9251 km^2 into the North Channel of Lake Huron. The upper basin consists mainly of rolling topography with numerous scattered lakes and swamps. Downstream of Aubrey Falls, the basin becomes more rugged with local relief frequently exceeding 150 m.

The Mississagi River is fed by tributaries, the Aubinadong, and Wenebegon Rivers in the northwest and the Little White River in the southeast. The Wenebegon River enters the Mississagi River just above Aubrey Falls, and the Aubinadong River confluence is about 13 km below Aubrey Falls. The Little White River enters the Mississagi River about 10 km upstream of Red Rock Falls.

The region experiences a temperate climate moderated by the Great Lakes. Daily mean temperature averages from -13°C in January to 17°C in July. Annual precipitation averages from 850 mm in the north to 900 mm in the south.

Three sub-basins within the Mississagi River watershed have been considered as potential candidates for fitting the streamflow forecasting models. These sub-basins were: Aubinadong River above Sesabic Creek sub-basin (drainage area of 1440 km^2), Little White River below Boland River sub-basin (1190 km^2) and Little White River near Bellingham (1960 km^2). Daily streamflow records date back to 1942 for the Little White River near Bellingham and to 1980 for the remaining two sub-basins. Flow records for both Little White River gauges are influenced by upstream regulation. However, the total storage volume available in three upstream reservoirs (Kindiogami Lake, Mount Lake, and Endikai Lake) is equivalent to less than 1 $m^3/s/day$; consequently, the effects of the regulation were disregarded in this study. Due to the time limitations only one of the three sub-basins can be analyzed and fitted with the forecasting models. Since the Little White River near Bellingham sub-basin had the longest period of streamflow data available, it was selected as the study area for this project.

Climate data necessary for models identification and calibration consisted of daily records of precipitation, maximum, minimum and average temperatures collected at five climate station in and around the Mississagi basin. Snow course records available were not used directly in the calibration process; however, they were helpful in establishing proper snow cover build-up in conceptual model calibration. The locations of climate and snow course stations are shown on Figure 2.

3. DETERMINISTIC PREDICTOR.

The Streamflow Synthesis and Reservoir Regulation (SSARR-8) computer model/9/ has been selected as a deterministic forecasting tool. It was developed by the U.S. Army Corps of Engineers to provide the planning, design and operation of water control works. The model was further developed for operational river forecasting and river management activities.

SSARR is a deterministic conceptual hydrologic model which synthesizes flow by simulating the physical processes affecting snowmelt and rainfall generated runoff. The basic routing method used in the model is a "cascade of reservoirs" technique, wherein the lag and attenuation of the flood wave are simulated through successive increments of lake-type storage. A watershed can be visualized as a series of small "lakes" which represent the natural delay of runoff from upstream to downstream points. The user specifies the routing characteristics of the prototype "lake" as well as the number of "lake" increments.

The successful calibration of the SSARR model is dependent upon the derivation of the various parameters and physical relationships specific to a particular watershed or river system. Some of the relationships can be observed or derived from recorded climatological data. Others must be considered as "model parameters" which have qualitative physical significance only. Watershed runoff characteristics (model calibration phase) can be determined by trial-and-error solutions using the computer program to obtain the best fit of historic streamflow data. This procedure is repeated until adequate verification of observed flows is obtained.

Streamflow records for the period of November 1979 - October 1989 have been selected for model calibration. Climate data required consisted of daily precipitation and maximum temperature recorded at the Mississagi Ontario Hydro station. Some data were missing from the Mississagi Ontario Hydro records. They were substituted by the available observations from other climate stations, namely Elliot Lake Denison, Elliot Lake Stanleigh, Montreal Falls, and Blind River.

Numerical values of the SSARR parameters and relationships obtained from the model calibration process are given in Table A1 in Appendix A. Statistics of model performance are shown in Table A2. Year-to-year performance of the calibration results can be best examined through comparison of recorded and computed hydrograps for each year of the calibration period. These are shown in Figures A1 to A5.

4. STOCHASTIC PREDICTORS

A certain number of stochastic models has been proposed in the technical literature /3/,/4/,/5/,/7/ for making forecasts of river flowrates, particularly in flood situations. The most common type of stochastic model proposed for describing the streamflow phenomena are the AutoRegressive Moving Average (ARMA) models (see/2/). The ARMA model of order (p,q) assumes that the current observation, y_t, is a linear combination of the past p observations y_{t-1}, ..., y_{t-p}, an unknown random shock (ncise term) a_t, and the past q shocks a_{t-1}, ..., a_{t-q}.

Let $y_t = w_t + \mu$, where μ is the mean of the series y_t. The model can be written as

$$w_t = \phi_1 w_{t-1} + \ldots + \phi_p w_{t-p} + a_t + \theta_1 a_{t-1} + \ldots + \theta_q a_{t-q}$$

Using a *backward-shift operator* B, which shifts time one step back in such a manner that $B^m y_t = y_{t-m}$, the ARMA(p,q) model can be written as:

$$\phi(B) w_t = \theta(B) a_t$$

where $\phi(B) = 1 - \phi_1 B - \ldots - \phi_p B^p$ and $\theta(B) = 1 - \theta_1 B - \ldots - \theta_q B^q$ are the autoregressive (AR) and moving average (MA) operators, respectively.

If the series y_t is nonstationary, which is usually the case for daily flows , it can be transformed into a stationary one by considering relevant differences $w_t = (1 - B)^d y_t$. The corresponding model can then be written as

$$\phi(B)(1 - B)^d (y_t - \mu) = \theta_o + \theta(B) a_t$$

This model is called the AutoRegressive Integrated Moving Average (ARIMA) model of the order (p,d,q).

The coefficients ϕ_i, i=1 ,..., p, are called the autoregressive parameters and they represent the weights given to previous observations. The coefficients θ_j, j=1 ,..., q, are called the moving average parameters and they represent the weights given to random shocks. It is assumed that the shocks a_t, t=1,2,... are normally distributed, uncorrelated random variables with zero mean and variance δ^2.

In order to identify the order of the model (the values of *p,q,* and *d*) a time series data set consisting of the daily streamflow records for the period between October 1982 and November 1986 has been selected. Although more streamflow data were available, the MacLeod-Hipel Time Series Package's/5/ memory restrictions did not allow the utilization of the whole set of recorded data.

Two different ARIMA type models have been identified for the Little White River subbasin, namely ARIMA(1,1,1) and ARIMA(1,2,2) models (see the autocorrelation functions, Figures B1 and B2 in Appendix B). The estimated values of the parameters for these models are given in Tables B1 and B2, respectively.

5. RESULTS

To assess the models performance, all three models were used to simulate forecasting of daily flows for 1, 2, 3, and 4 days ahead. The simulation consisted of running the calibrated model for forecasting of 4 consecutive days for each day in the study period. For the SSARR model the observed temperature and precipitation data were used as perfect meteorological predictions. For ARIMA models future values of random shocks were set to zero, and past values were calculated as the difference between the observed and predicted values. The models were run interactively and the predicted streamflow for a given day was updated to the recorded value before the model was restarted for the next four consecutive days. The Nash Coefficient (CNA), used in the study as a performance criterion, is defined as

$$CNA = 1 - \frac{\Sigma(Q_o - Q_f)^2}{\Sigma(Q_o - \overline{Q}_o)^2}$$

where Q_o are observed, and Q_f predicted, flows for a given period of time.

A four-year period (November 1975 to October 1979) was selected for forecasting simulation. The simulation results, shown in Table 1 and on Figures 3.1 to 13.4, illustrate the ability of all three models to meet, and in most cases, significantly exceed, the performance requirements. It should be noted that the CNA values were calculated for flood events only; the periods of prolonged steady flows were excluded from CNA calculations, thus preventing it from being artificially high.

6. OBSERVATIONS AND CONCLUSIONS

One conceptual hydrologic model and a class of stochastic ARIMA models were considered in this study. Although it was not mentioned earlier in the report, a class of transfer function-noise (TFN) models, using original and cumulative temperature and precipitation series as an exogenous input, was tested as an alternative to the ARIMA models. However, due to the computer software limitations and time restrictions, the resulting performance of the TFN models was substantially inferior to that of ARIMA models.

Analysis of performance results indicates that the SSARR model has better forecasting abilities for snowmelt related events. Performance indices for spring events in the 4-year period significantly exceeded user requirements and were also better than corresponding values obtained from the ARIMA models. It should not be surprising if one takes into ac-

count that SSARR uses the temperature data to compute the forecast, and temperature is the deciding factor governing the speed and the magnitude of the melting process. It should be pointed out also that temperature records are much more reliable sources of climatic information since, unlike precipitation data, they are not susceptible to intense but local phenomena.

The advantage of using climate data during snowmelt periods can become a liability when the precipitation is the only factor contributing to sudden streamflow changes during rainfall-runoff events. In 3 out of 7 non-spring events during 1975-1979 period, one or both of ARIMA models perform better than SSARR. The lower accuracy of the SSARR model, especially during summer periods, can be explained by the presence of high intensity, local storms which might have occurred in the basin but were not recorded by the climate station, and vice versa.

With the exception of only two cases (snowmelt floods of 1975 and 1977) the ARIMA(1,2,2) model performs better than the ARIMA(1,1,1) model; consequently, is considered preferable as a forecasting tool.

Preliminary analysis of the Aubinadong River sub-basin, located farther north, indicates that its hydrological characteristics are different from these obtained for the Little White River watershed. Consequently, one may expect that at least part of the modeling efforts have to be repeated if the forecasting tools for this sub-basin are also required. However, a closer look at Aubinadong River sub-basin may be worthwhile because this area may offer better representation of precipitation conditions due to the presence of two more climate stations in the area's vicinity (Biscotasing and Montreal Falls). It is expected that more accurate precipitation records should improve the performance of both conceptual and stochastic models.

Approved:

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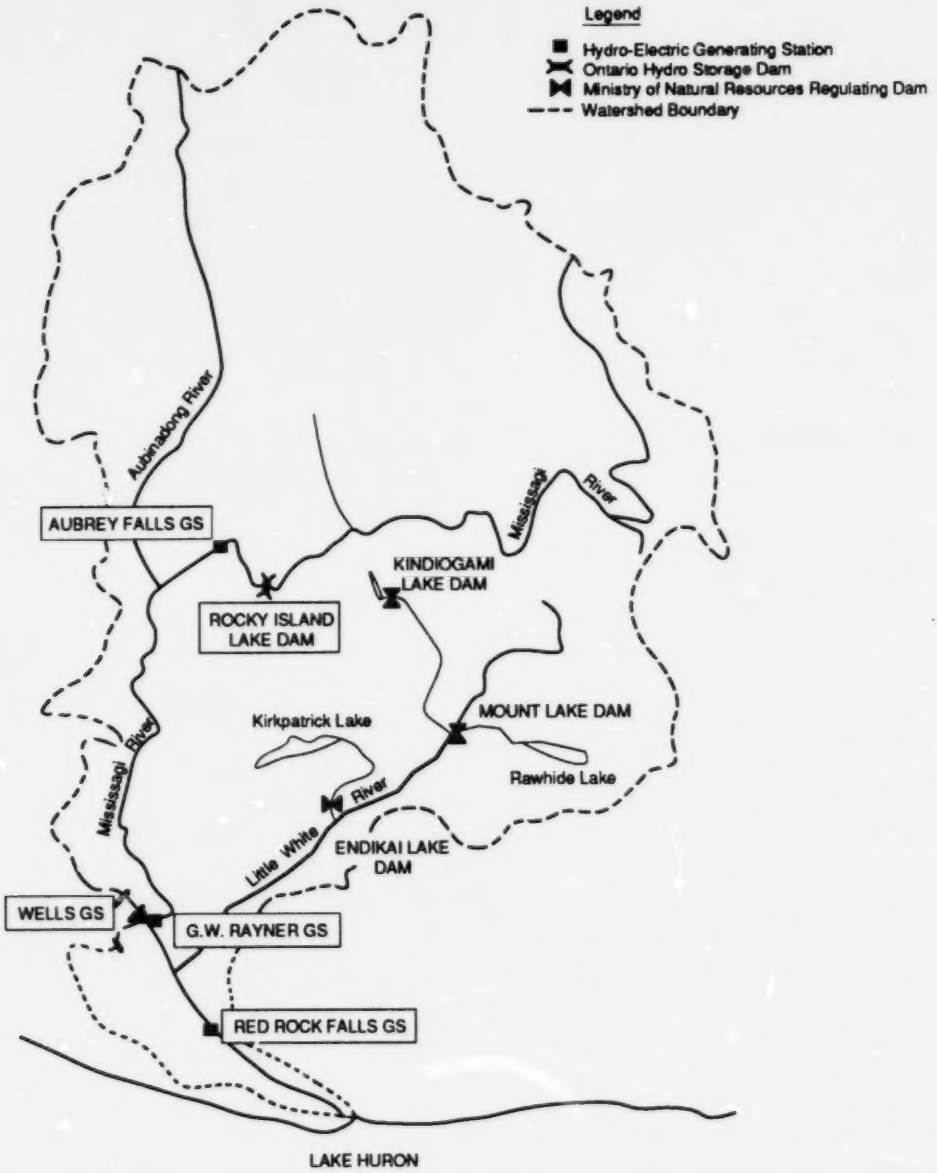

Figure 1 Map of the Study Area

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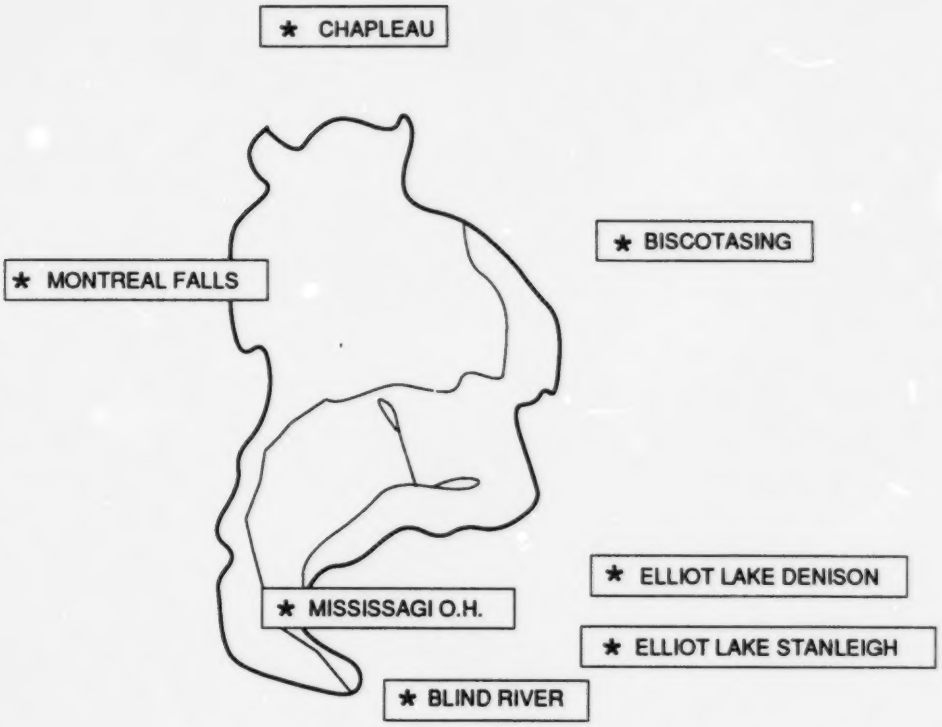

Figure 2 Climate Stations (★)

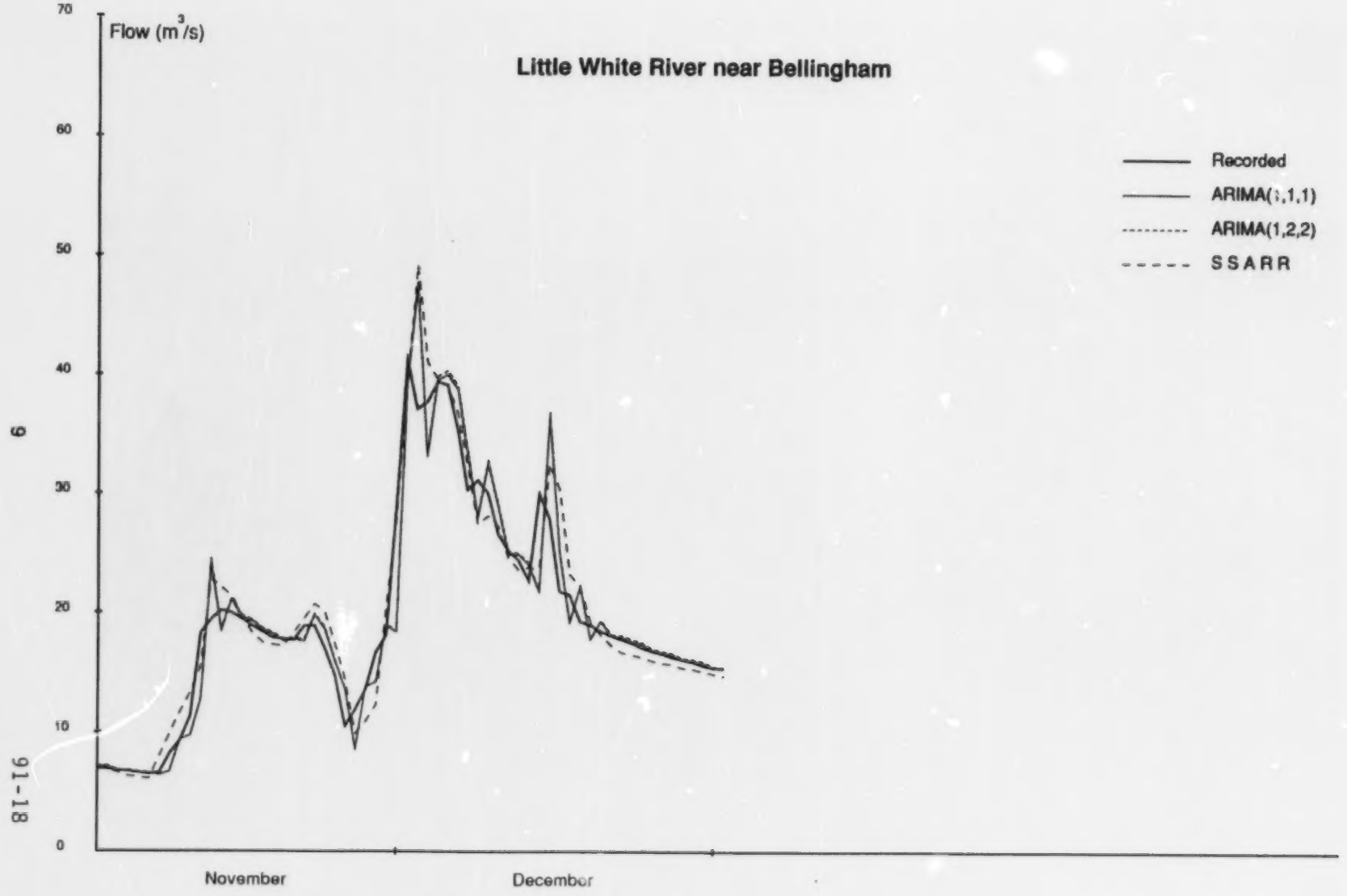

Figure 3.1 1-Day Ahead Forecast (2 November - 31 December 1975)

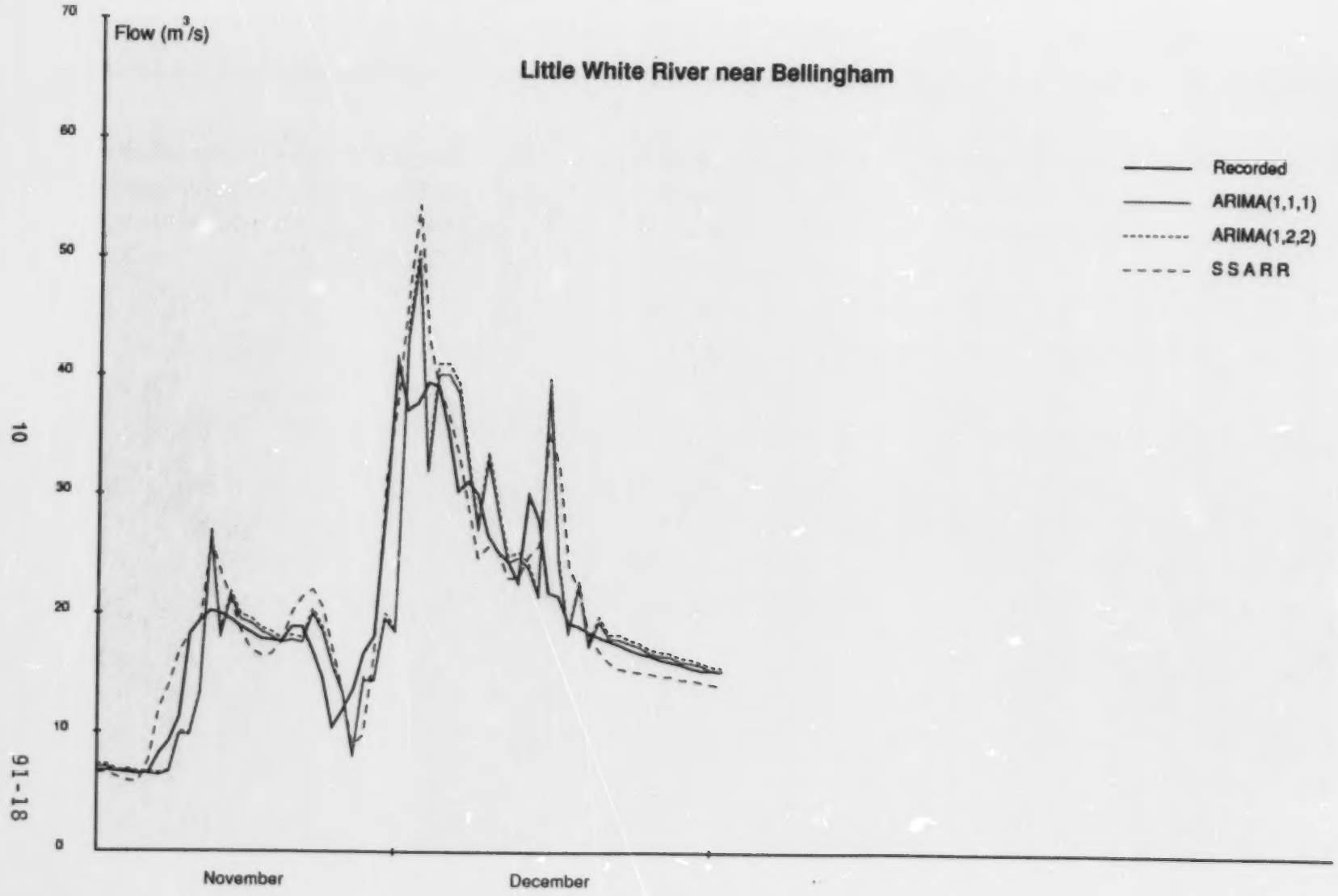

Figure 3.2 2-Days Ahead Forecast (2 November - 31 December 1975)

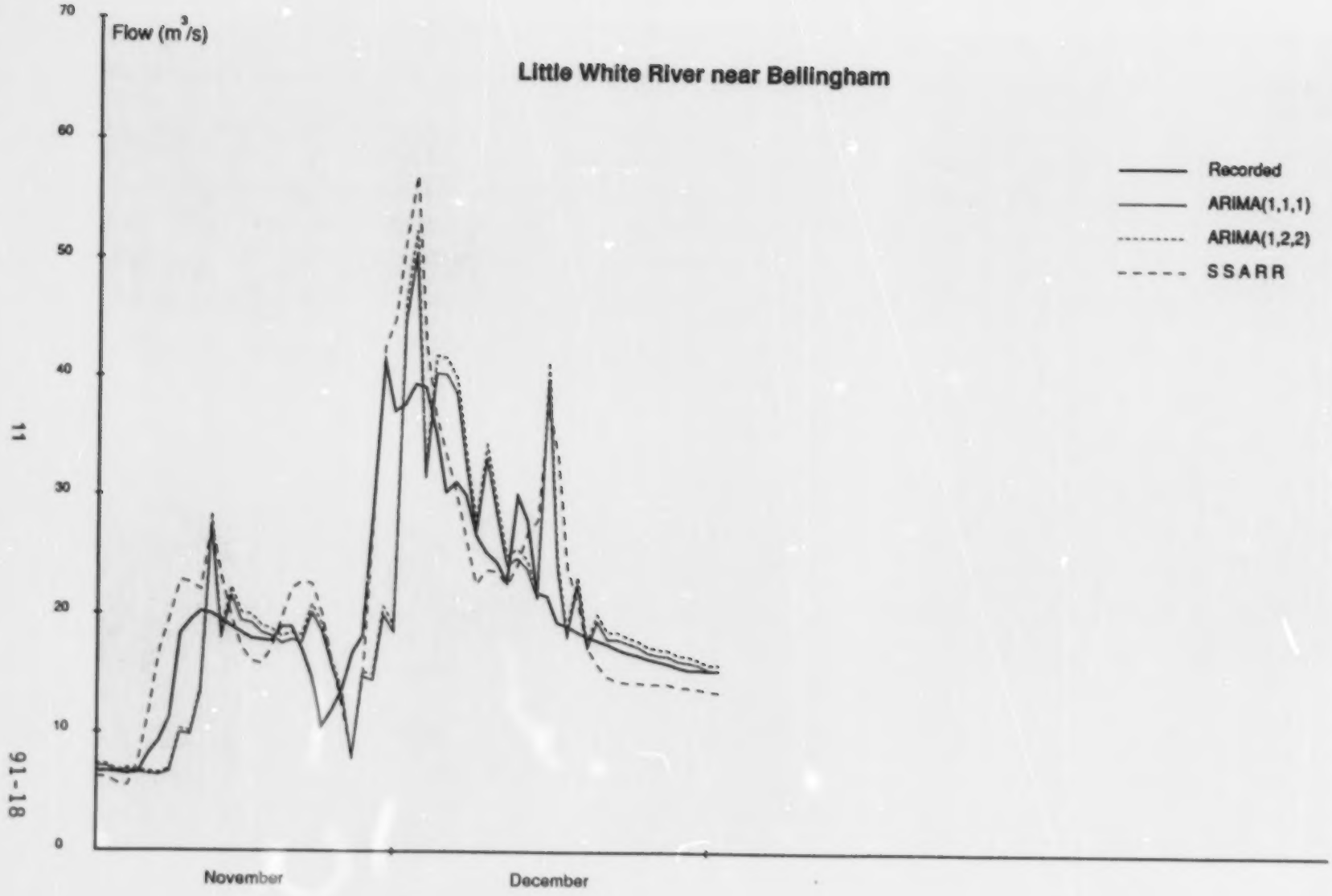

Figure 3.3 3-Days Ahead Forecast (2 November - 31 December 1975)

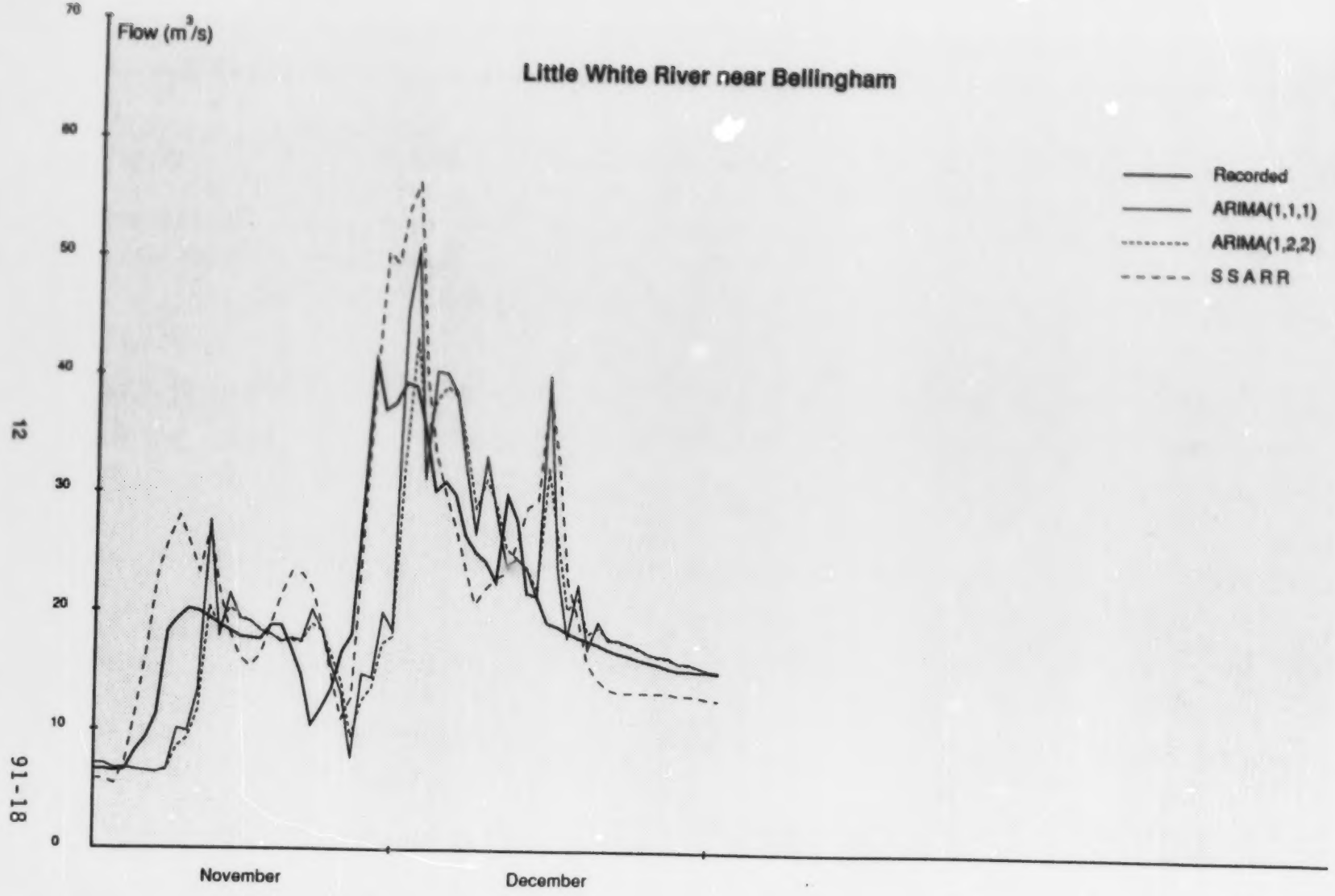

Figure 3.4 4-Days Ahead Forecast (2 November - 31 December 1975)

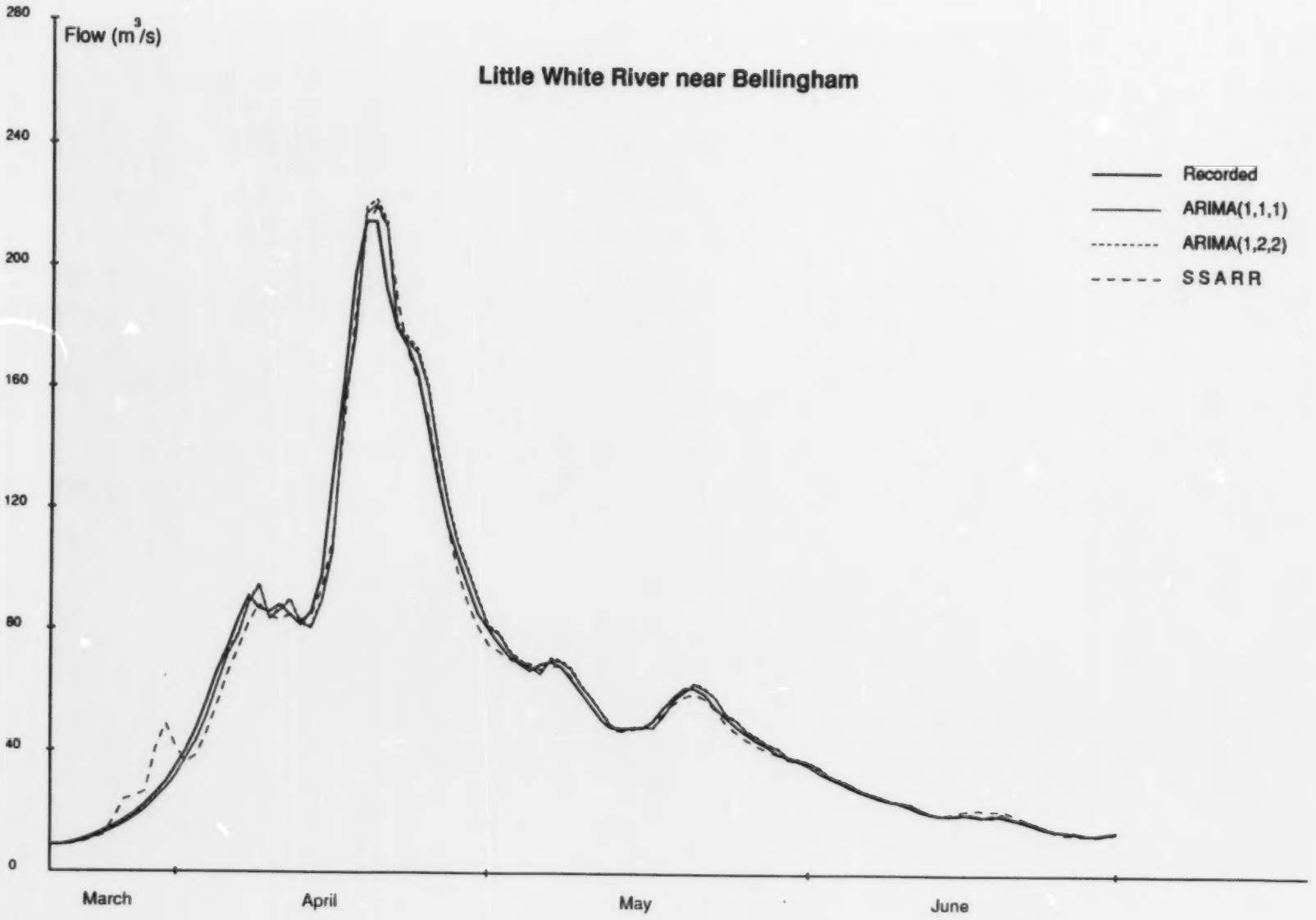

Figure 4.1 1-Day Ahead Forecast (20 March - 30 June 1976)

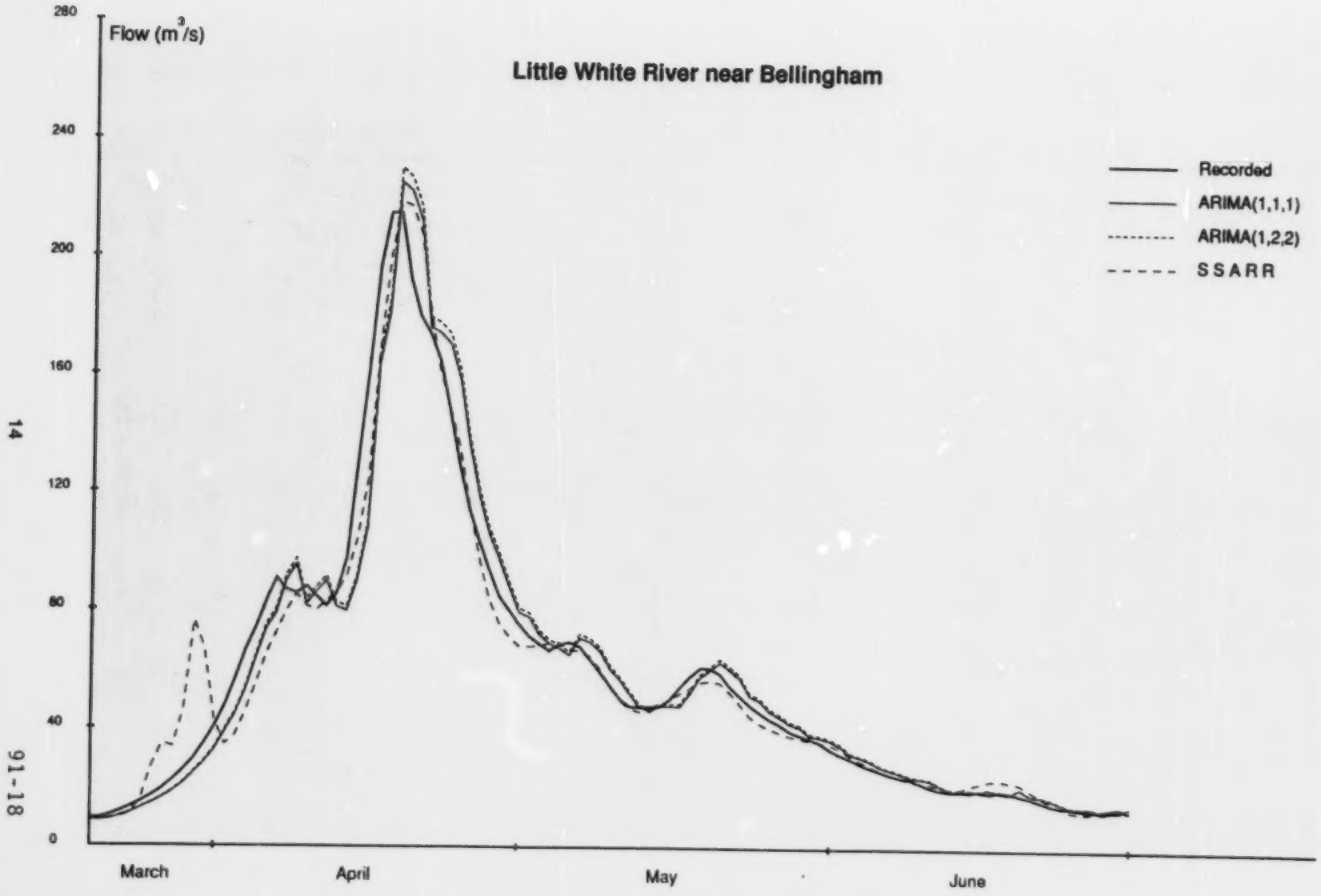

Figure 4.2 2-Days Ahead Forecast (20 March - 30 June 1976)

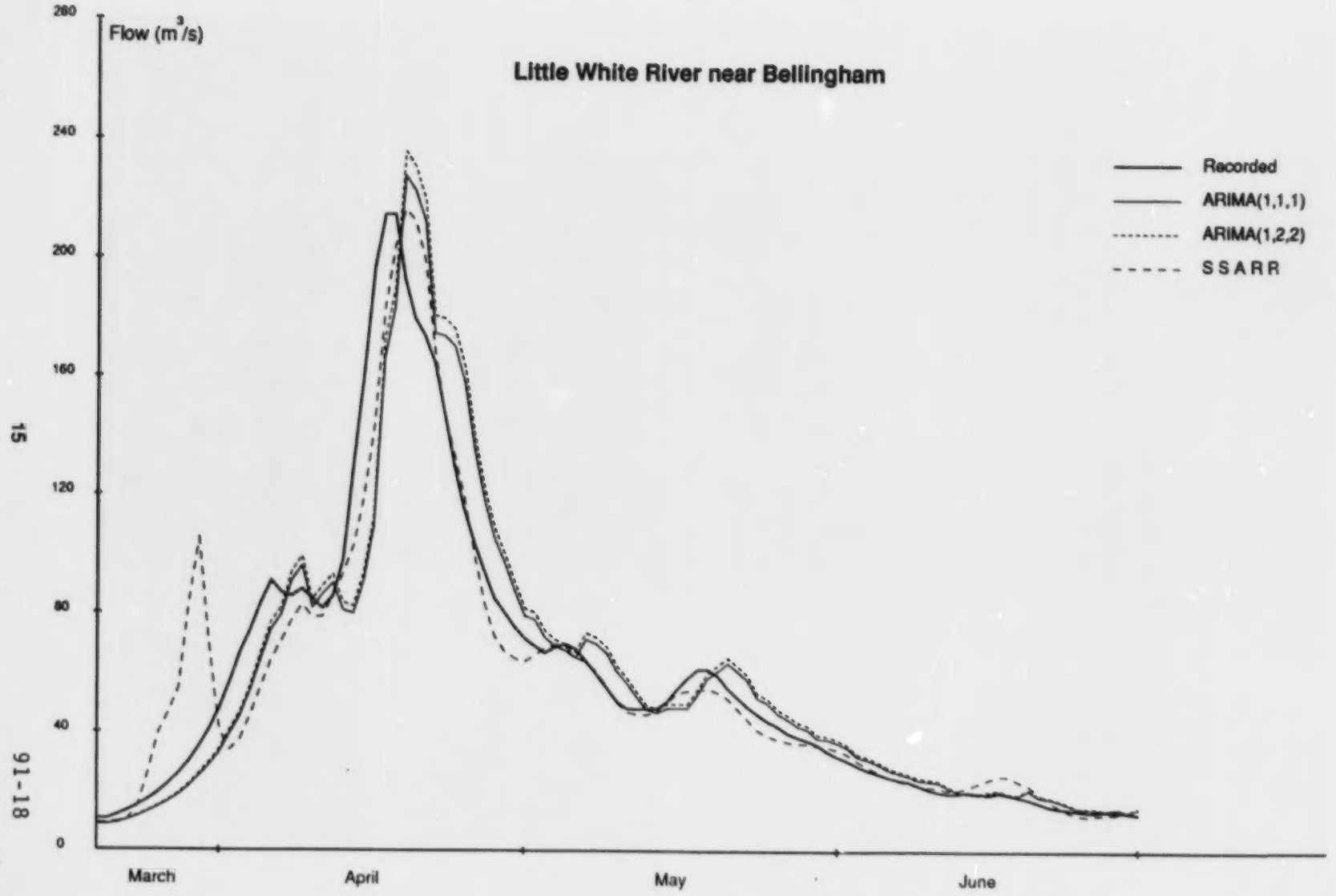

Figure 4.3 3-Days Ahead Forecast (20 March - 30 June 1976)

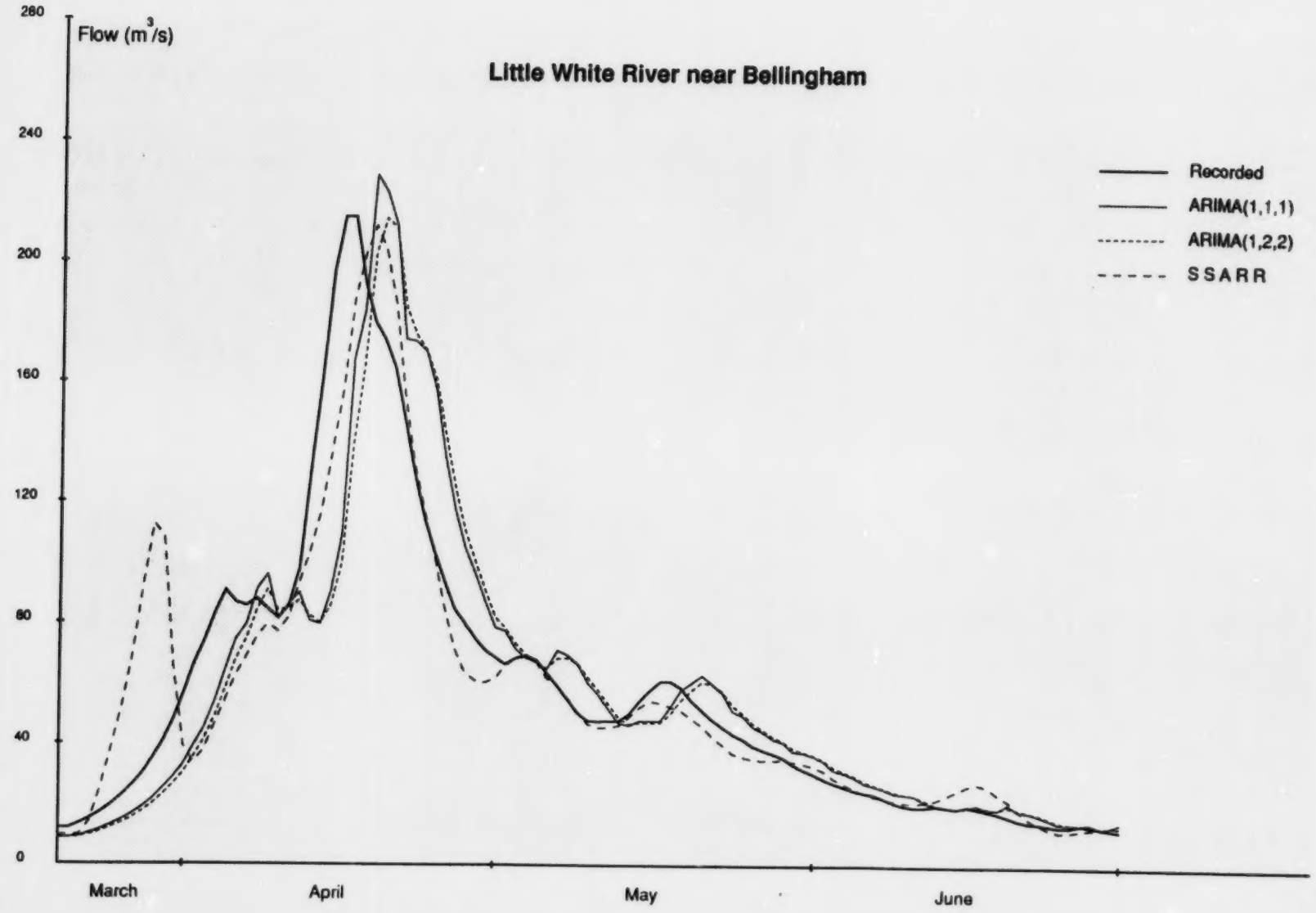

Figure 4.4 4-Days Ahead Forecast (20 March - 30 June 1976)

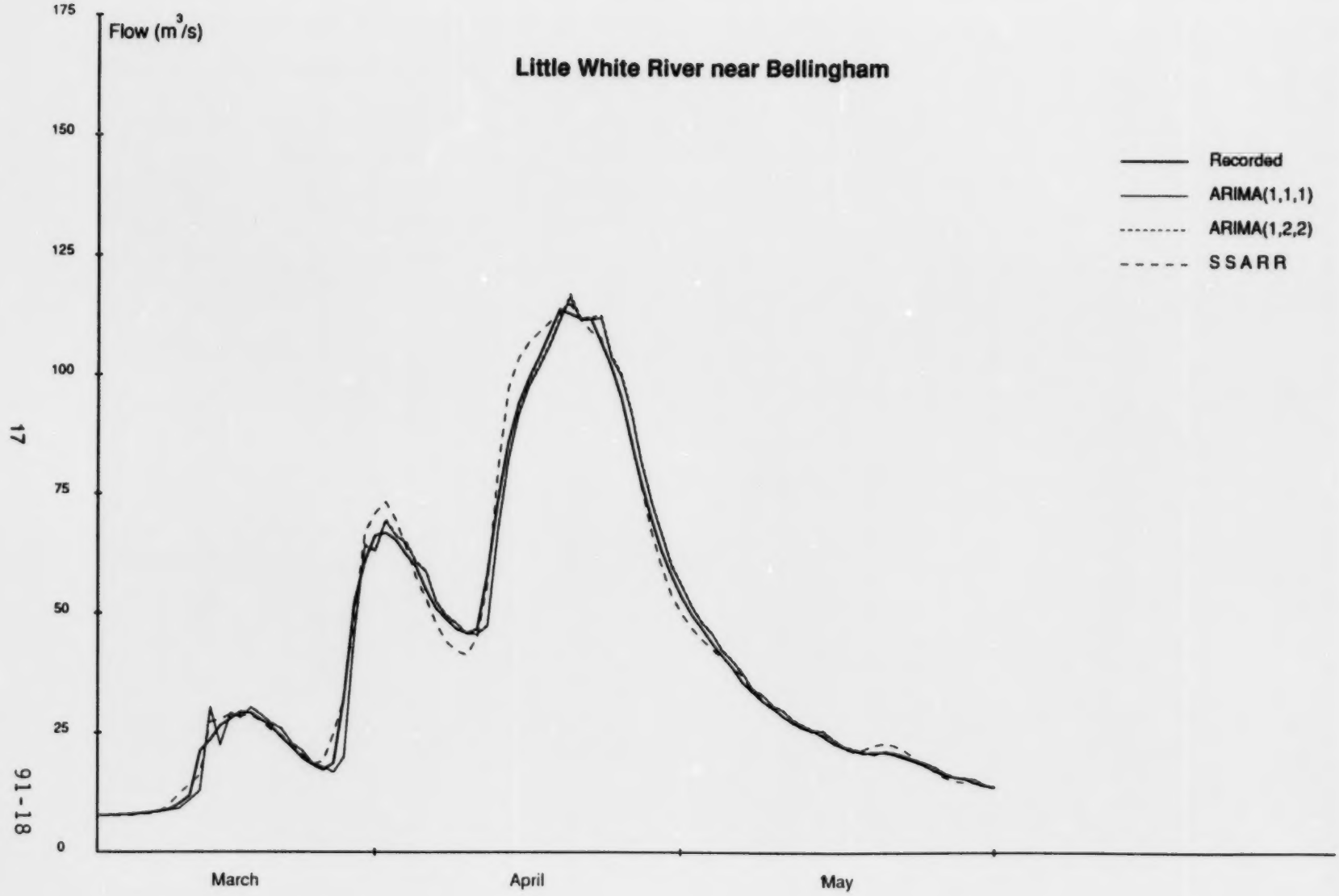

Figure 5.1 1-Day Ahead Forecast (5 March - 31 May 1977)

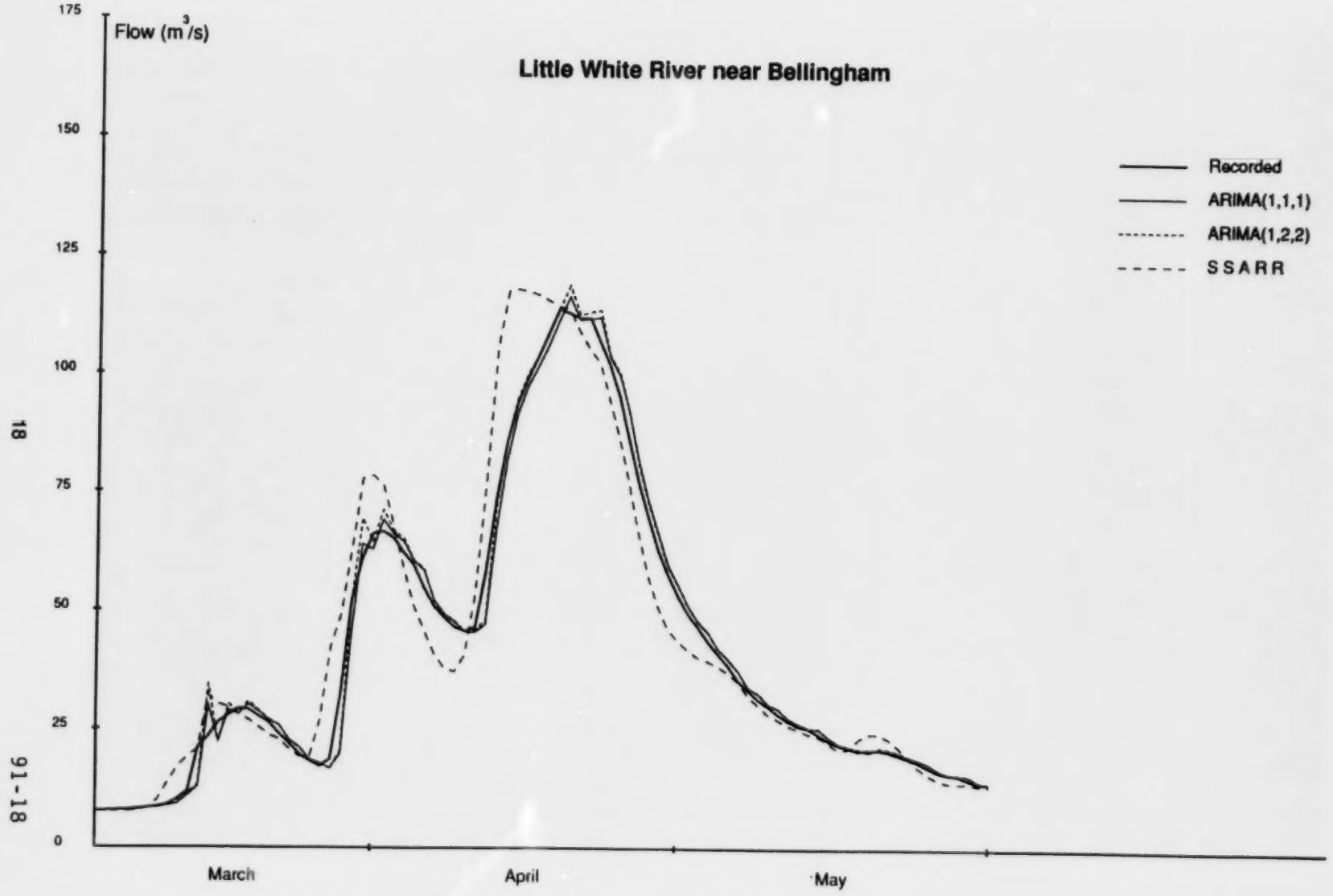

Figure 5.2 2-Days Ahead Forecast (5 March - 31 May 1977)

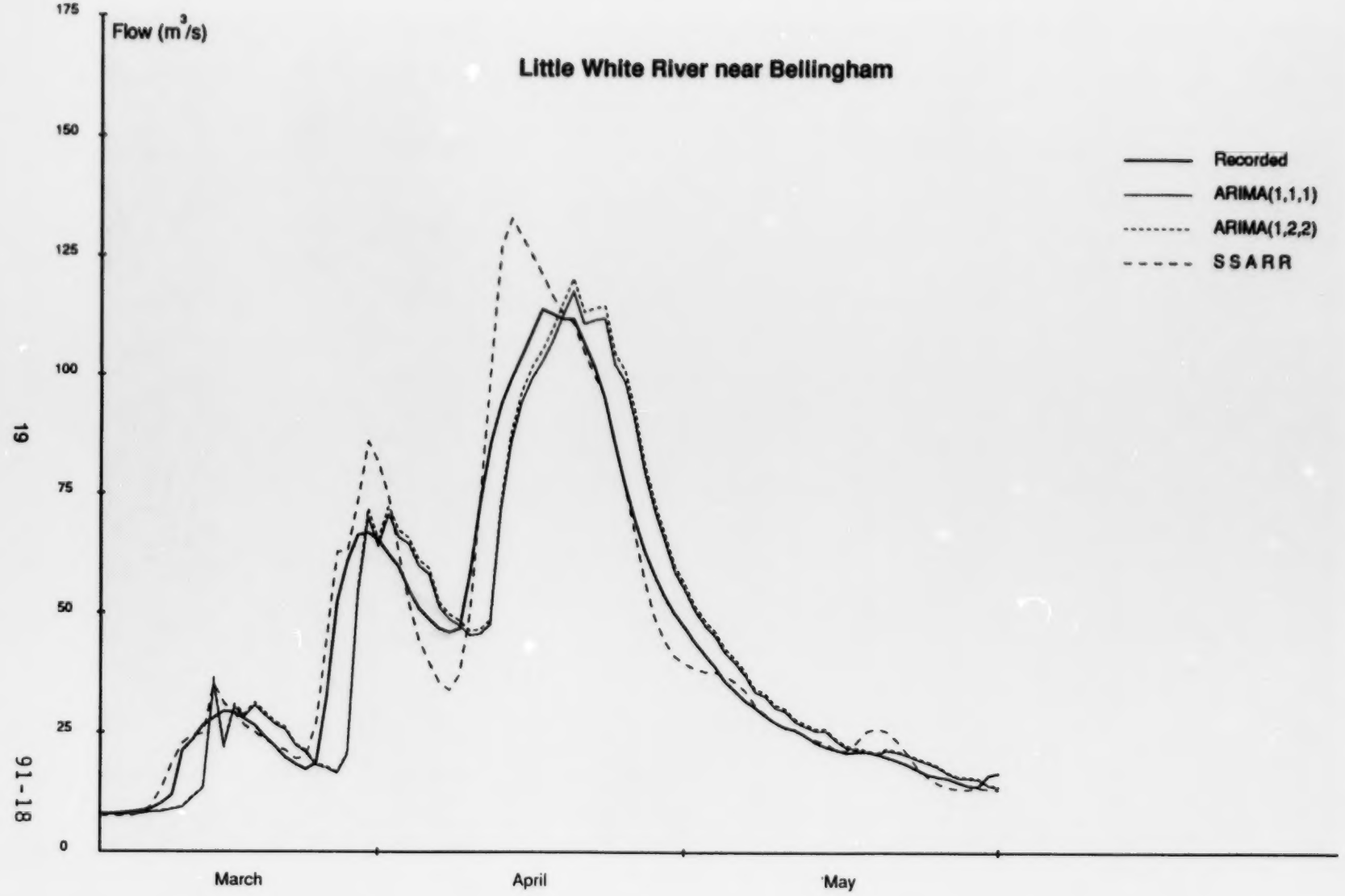

Figure 5.3 3-Days Ahead Forecast (5 March - 31 May 1977)

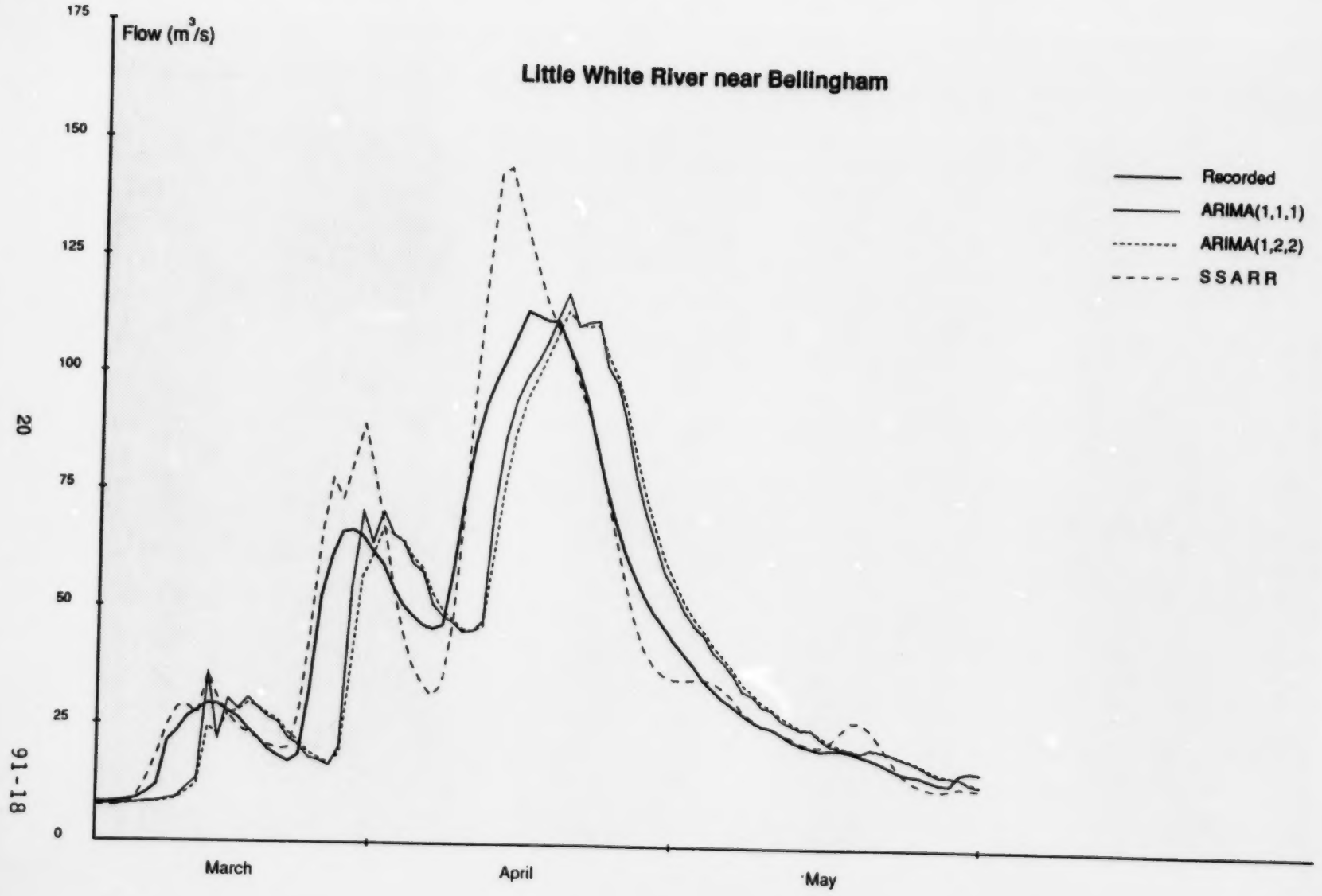

Figure 5.4 4-Days Ahead Forecast (5 March - 31 May 1977)

Figure 6.1 1-Day Ahead Forecast (25 June - 25 July 1977)

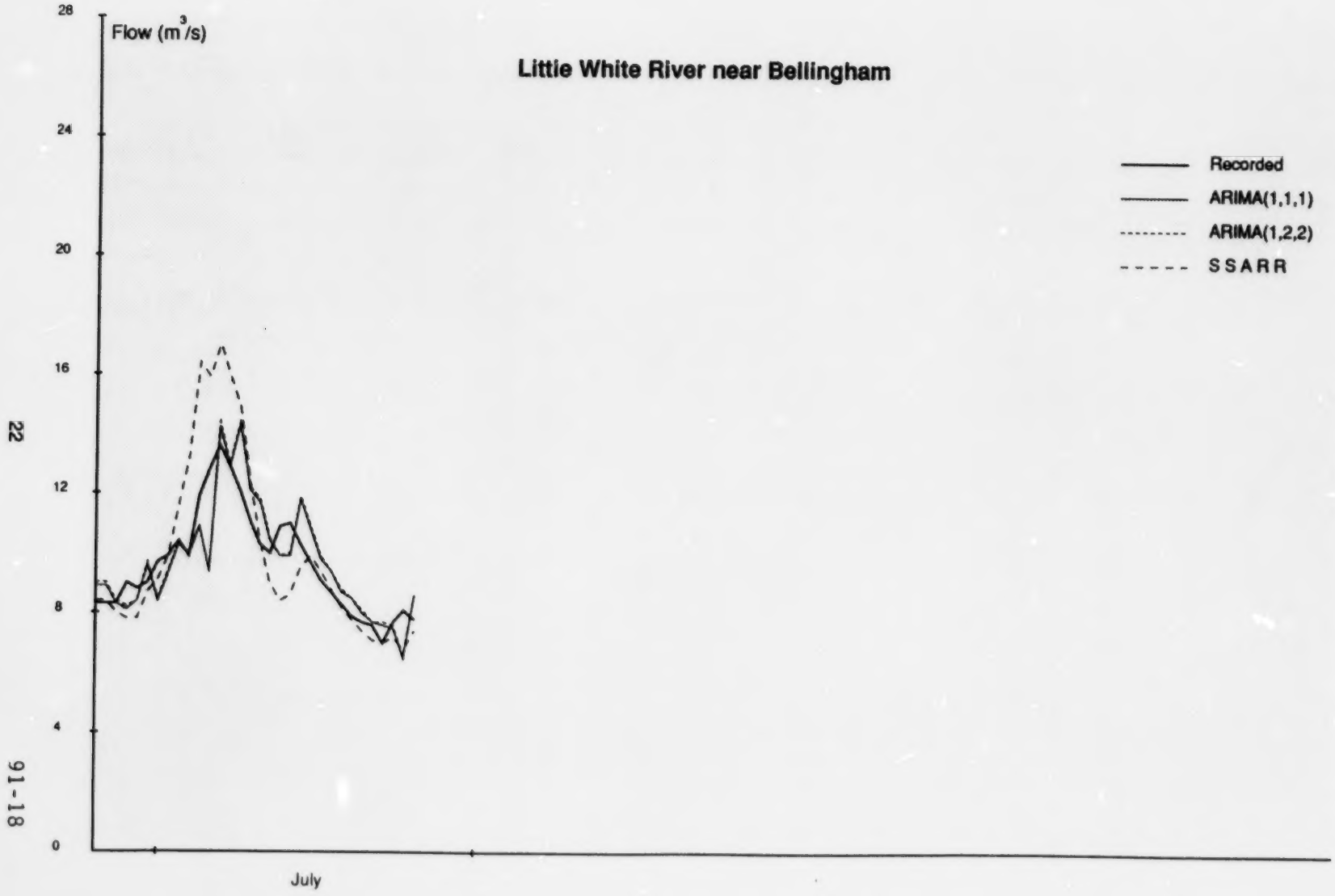

Figure 6.2 2-Days Ahead Forecast (25 June - 25 July 1977)

Figure 6.3 3-Days Ahead Forecast (25 June - 25 July 1977)

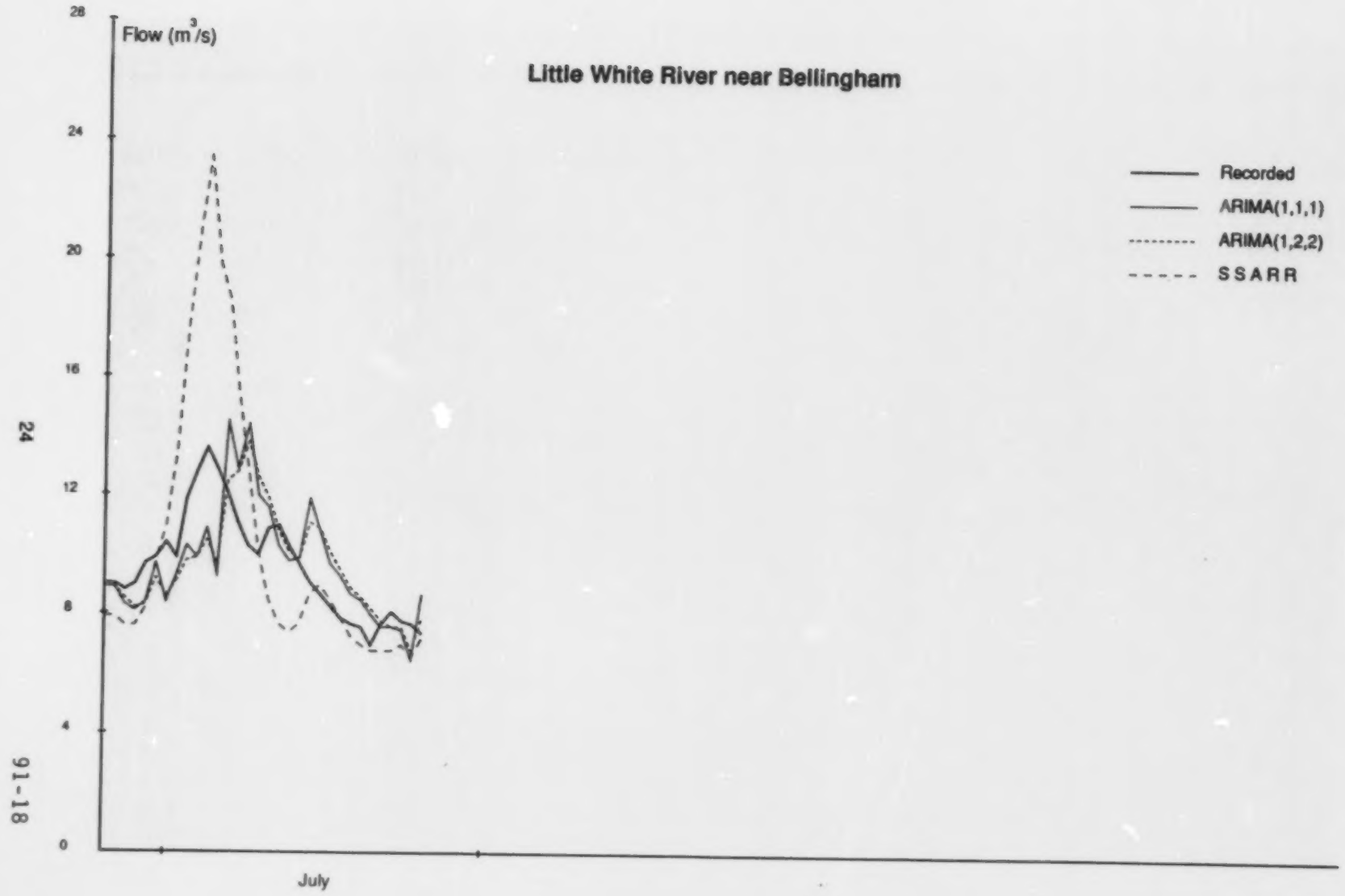

Figure 6.4 4-Days Ahead Forecast (25 June - 25 July 1977)

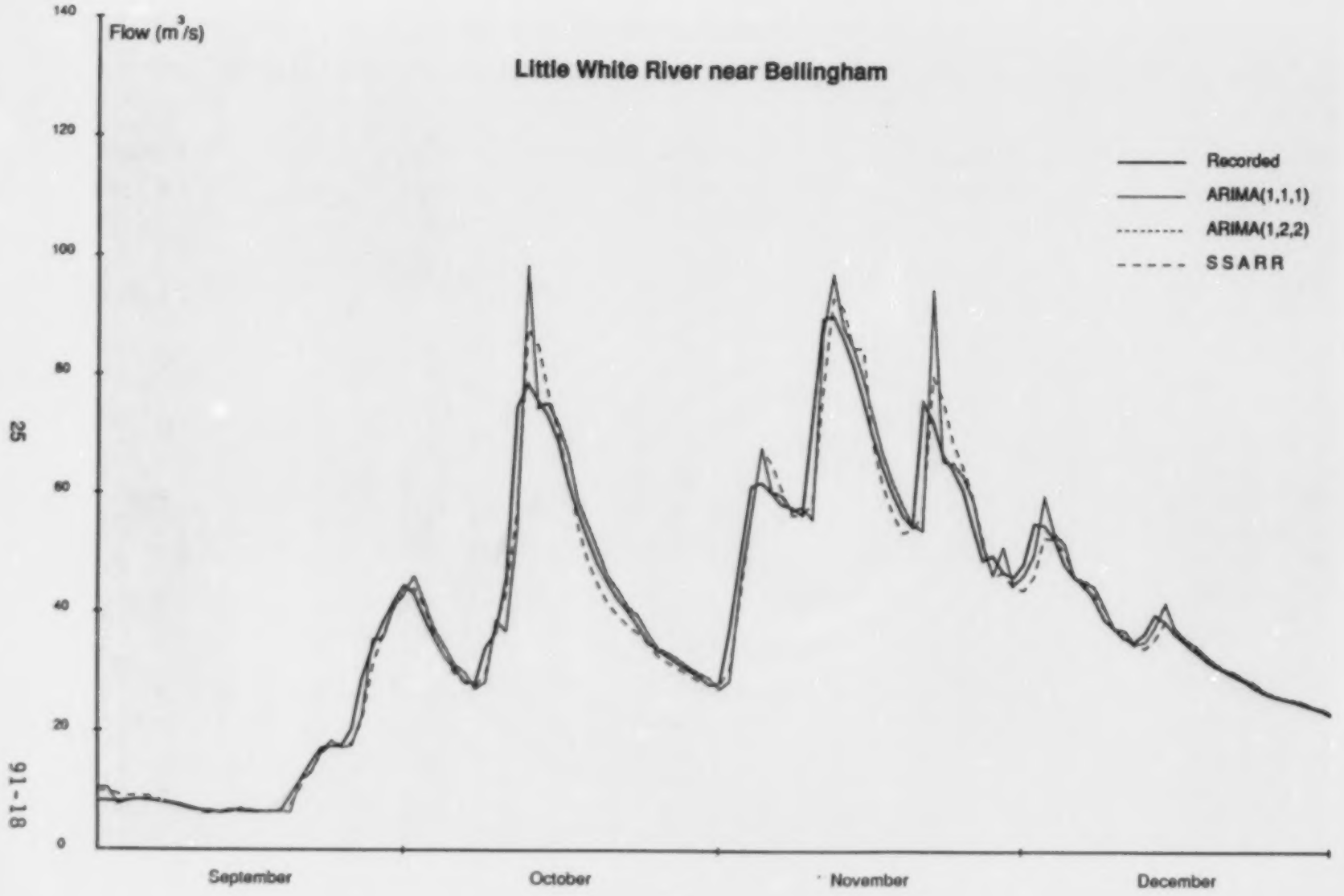

Figure 7.1 1-Day Ahead Forecast (1 September - 31 December 1977)

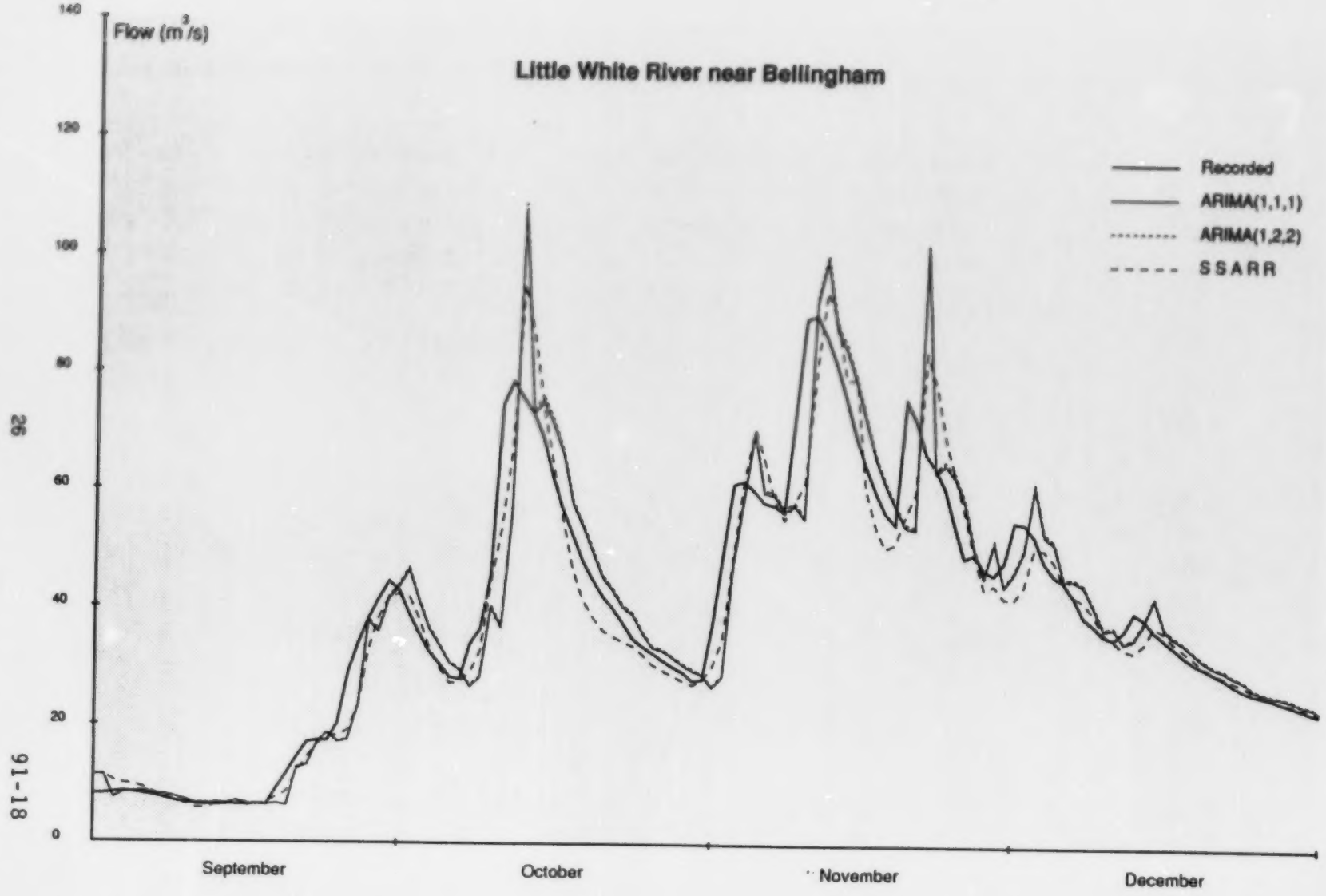

Figure 7.2 2-Days Ahead Forecast (1 September - 31 December 1977)

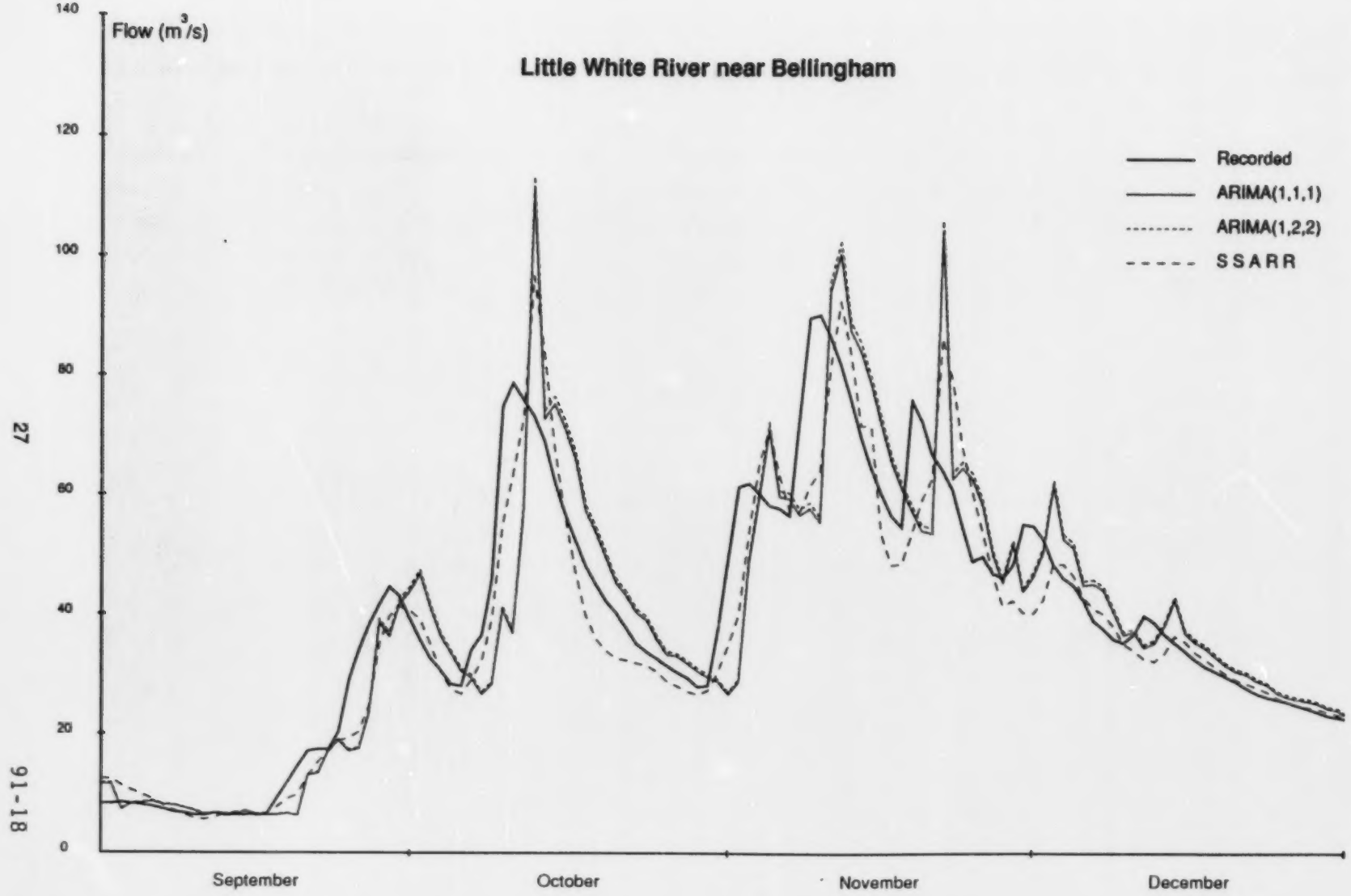

Figure 7.3 3-Days Ahead Forecast (1 September - 31 December 1977)

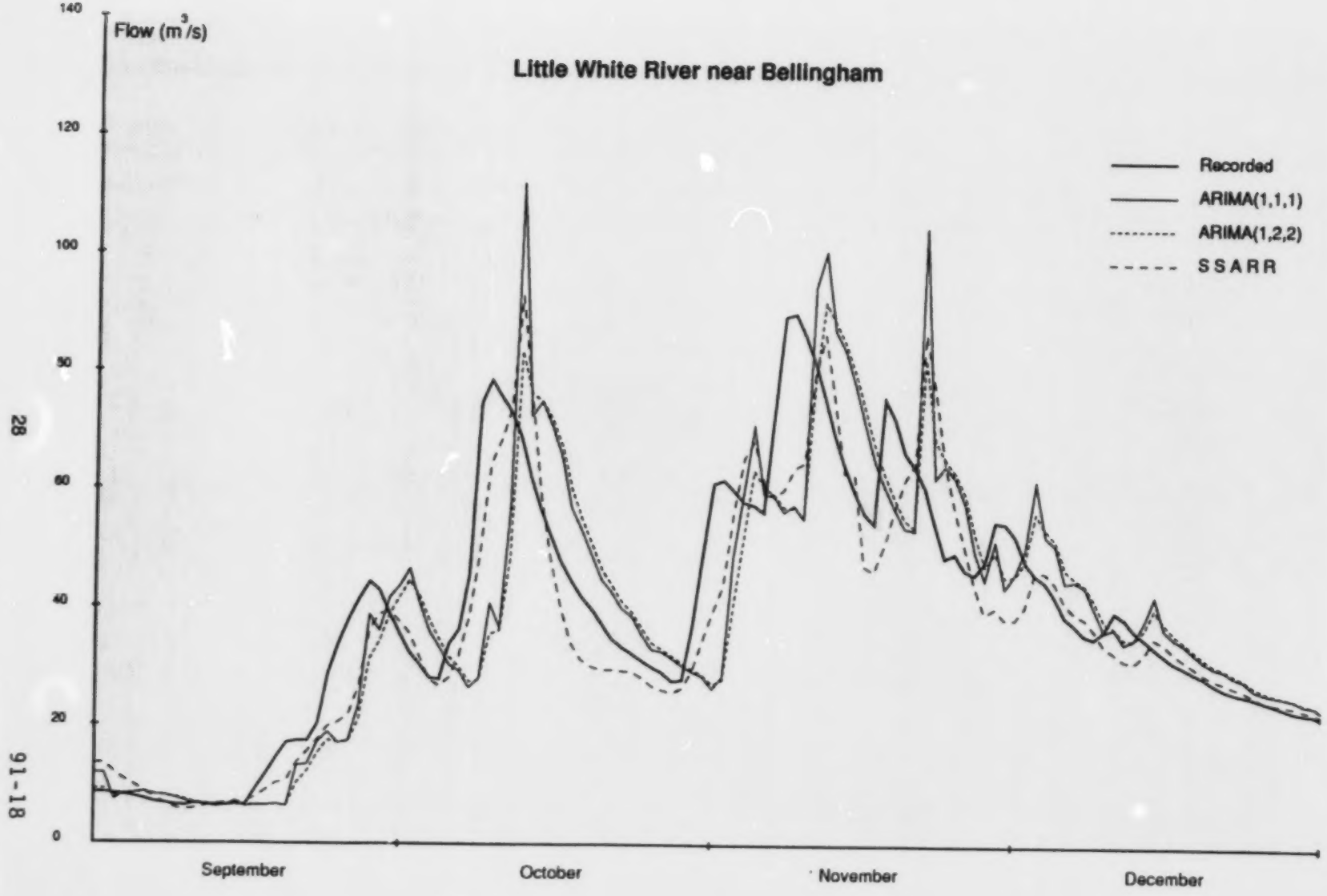

Figure 7.4 4-Days Ahead Forecast (1 September - 31 December 1977)

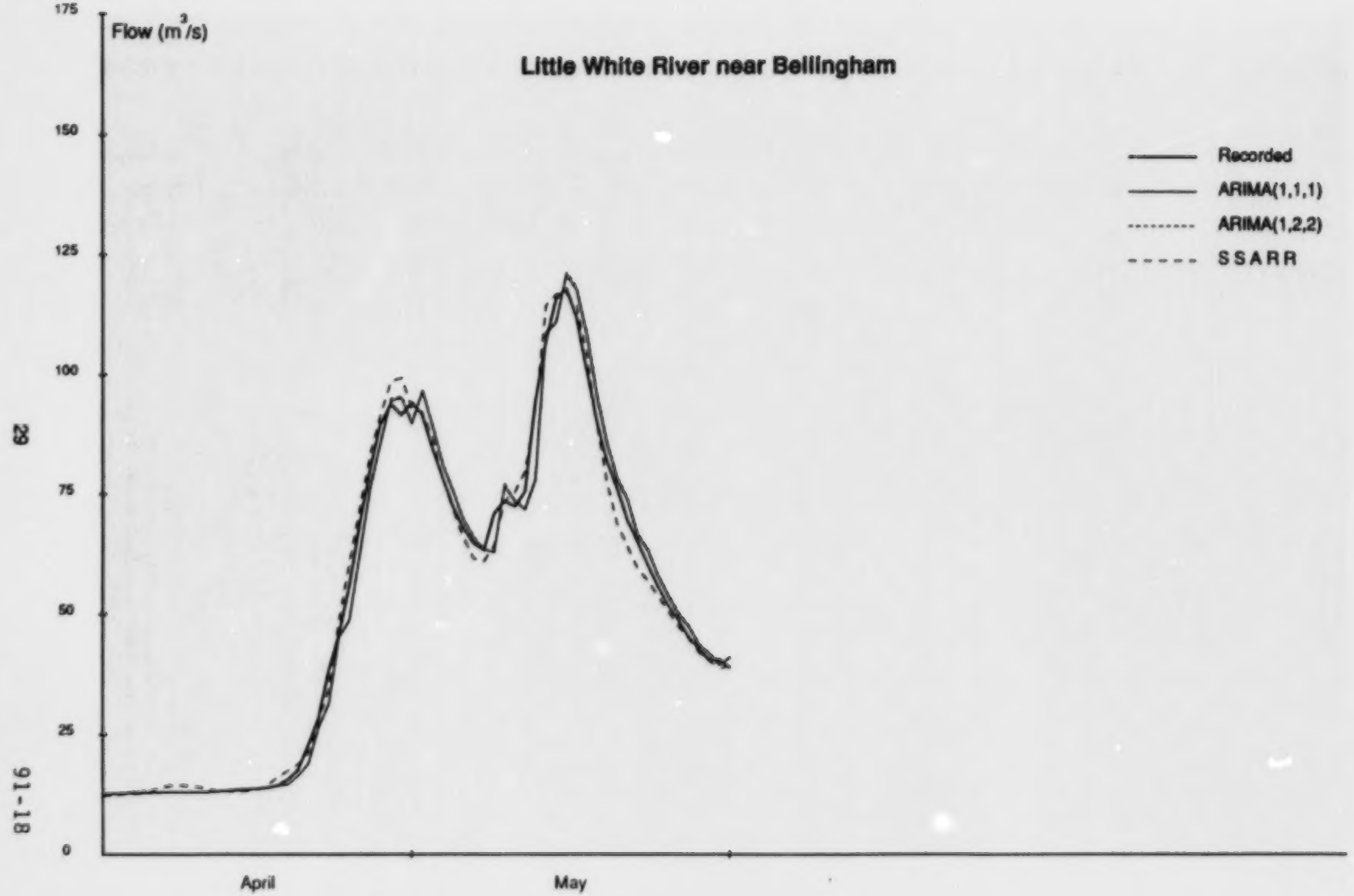

Figure 8.1 1-Day Ahead Forecast (1 April - 31 May 1978)

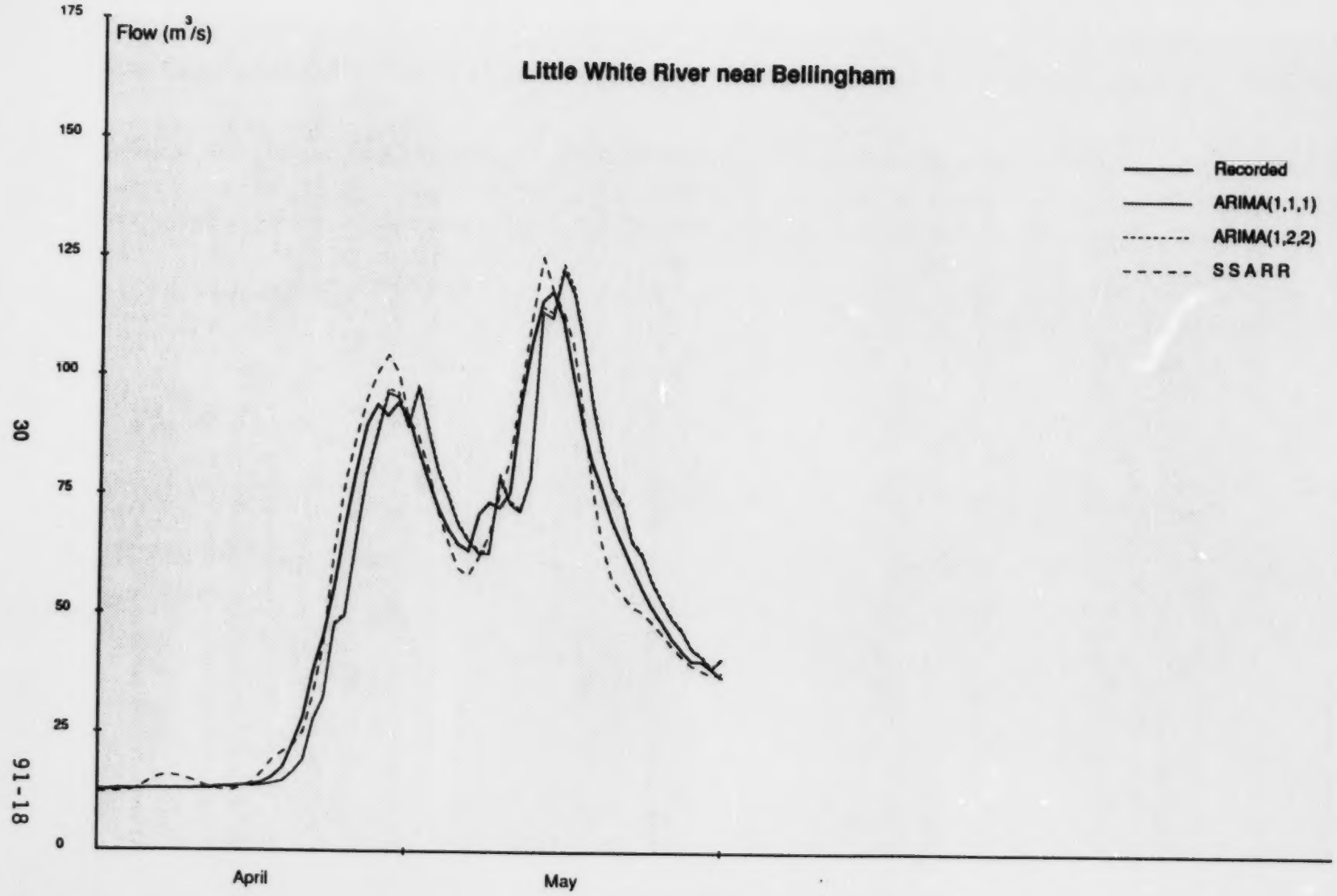

Figure 8.2 2-Days Ahead Forecast (1 April - 31 May 1978)

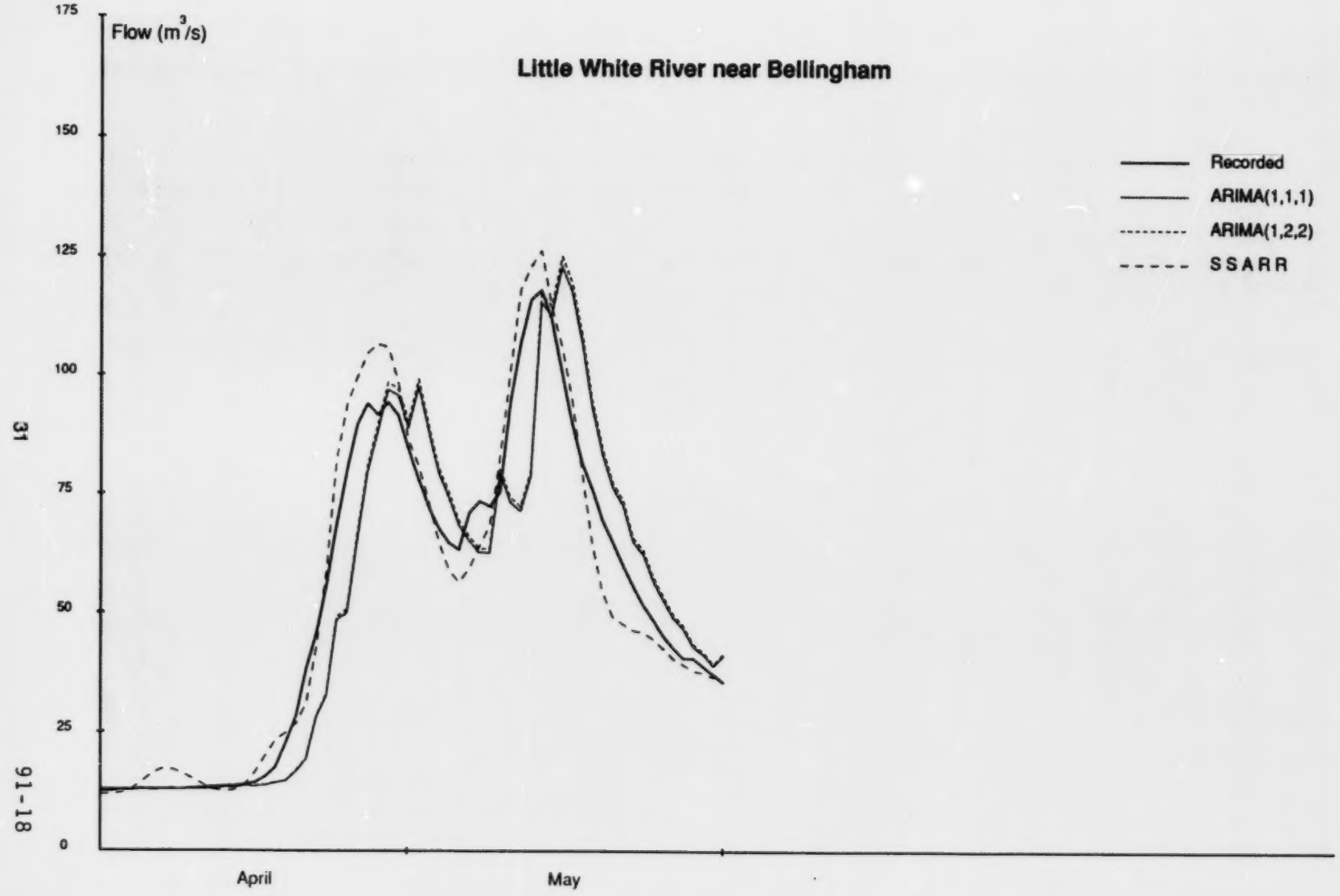

Figure 8.3 3-Days Ahead Forecast (1 April - 31 May 1978)

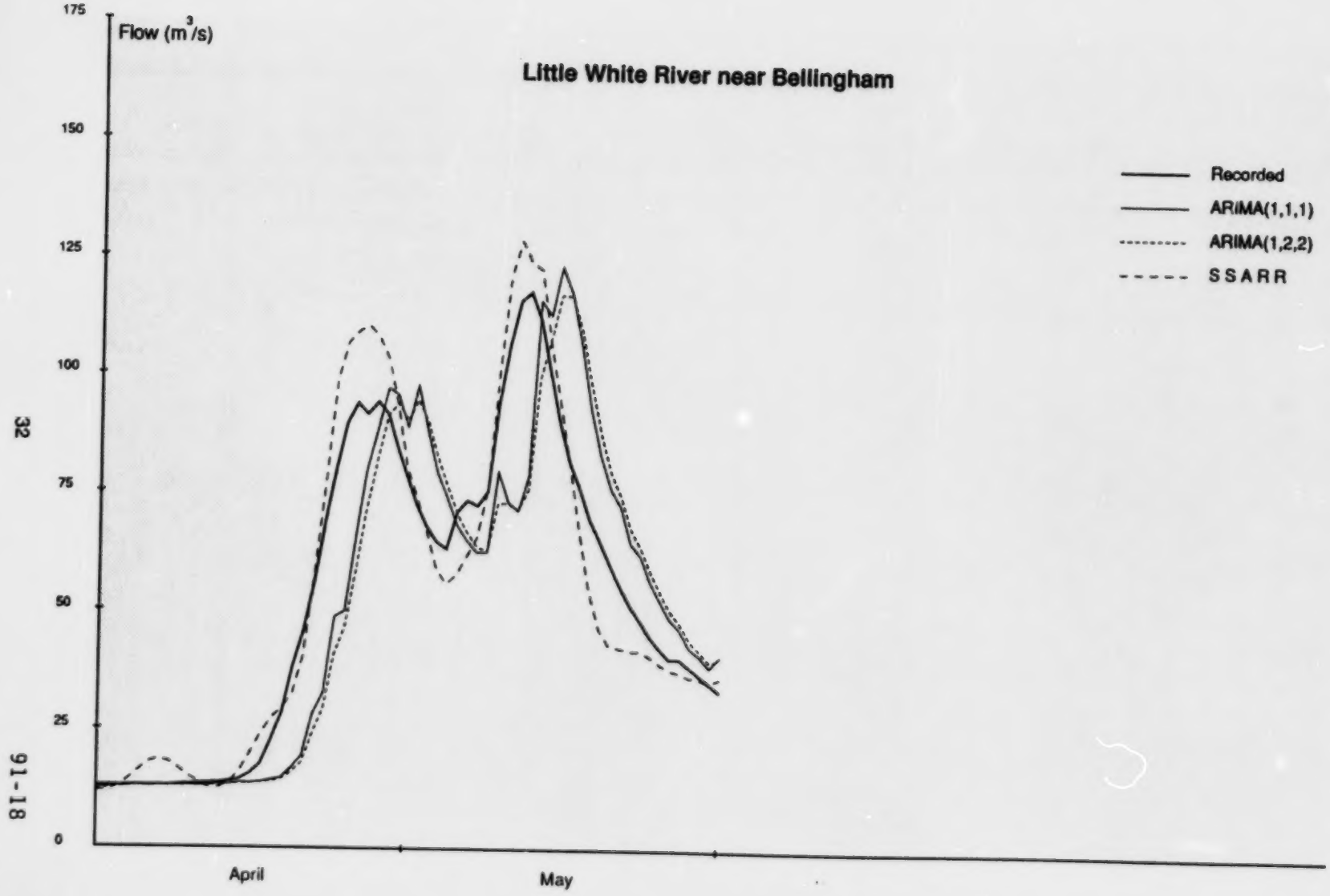

Figure 8.4 4-Days Ahead Forecast (1 April - 31 May 1978)

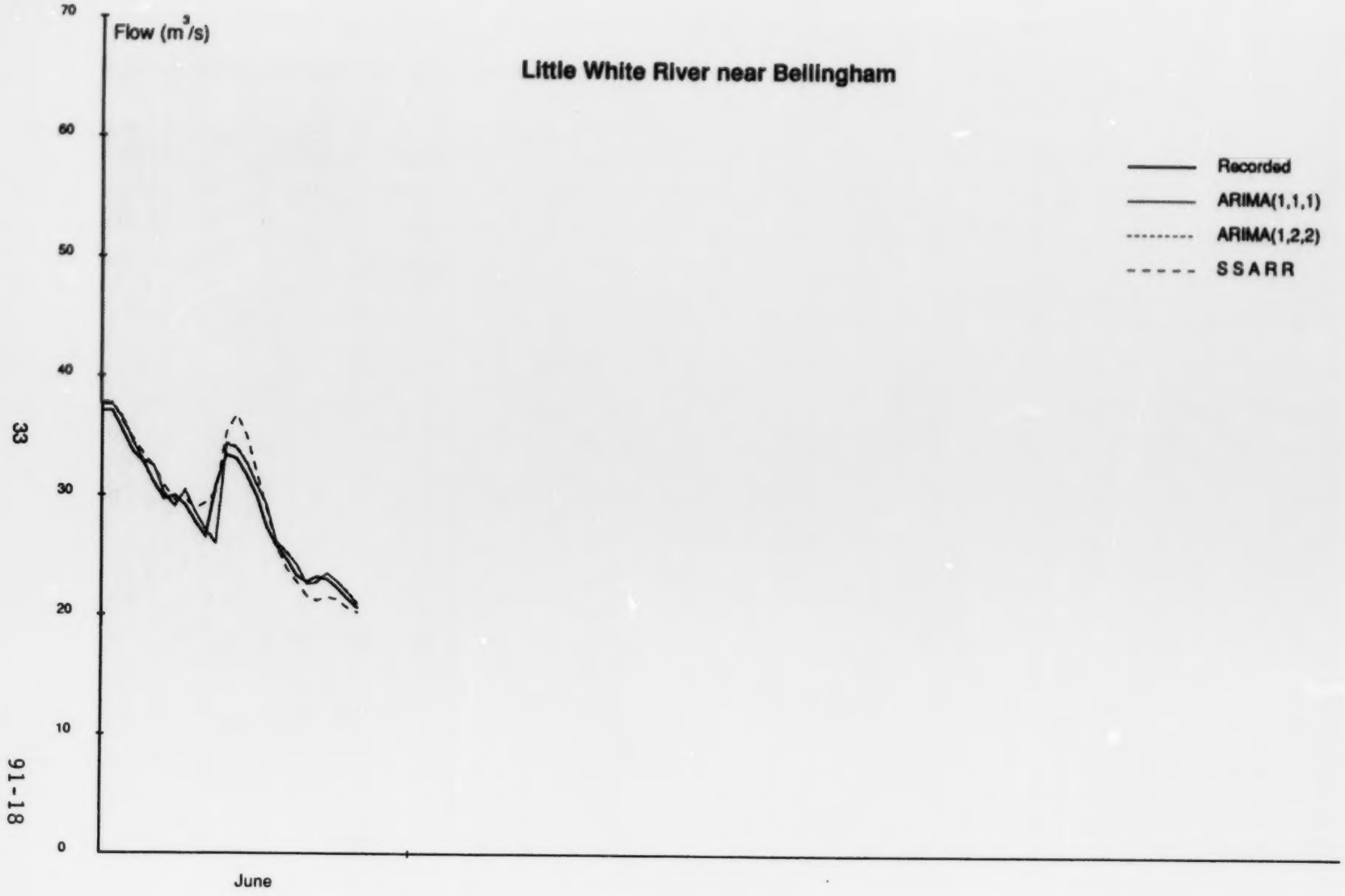

Figure 9.1 1-Day Ahead Forecast (1 June - 25 June 1978)

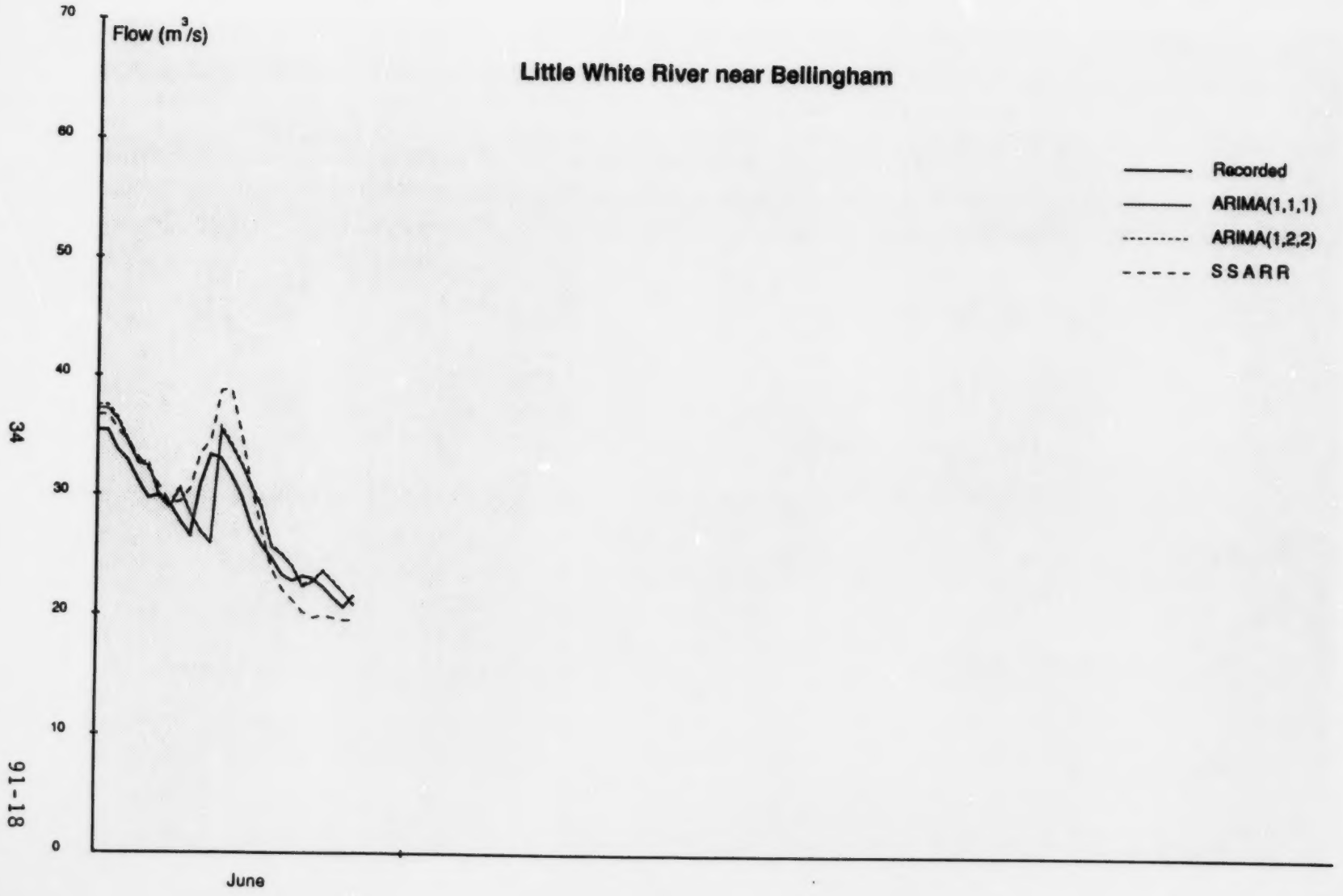

Figure 9.2 2-Days Ahead Forecast (1 June - 25 June 1978)

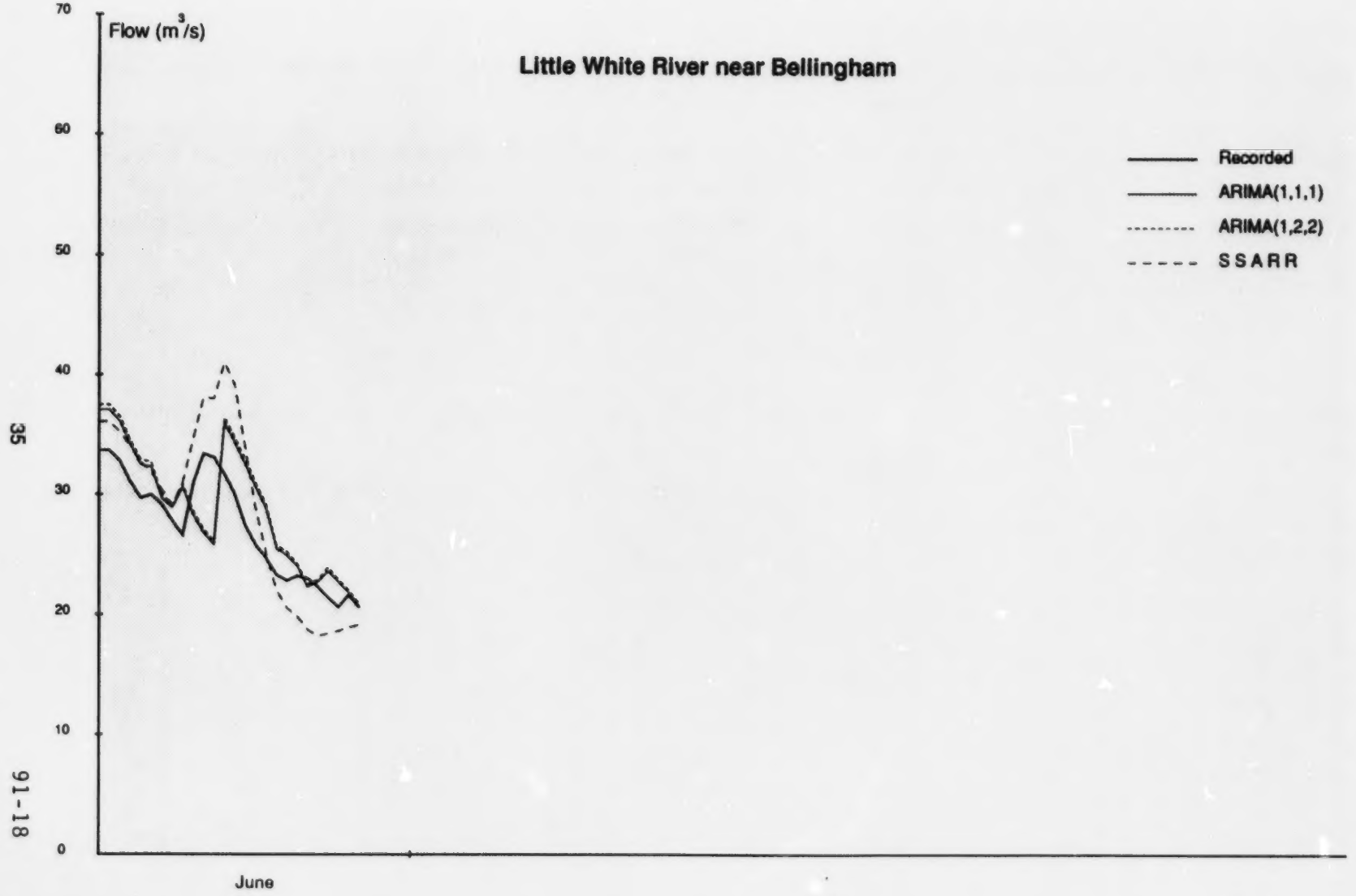

Figure 9.3 3-Days Ahead Forecast (1 June - 25 June 1978)

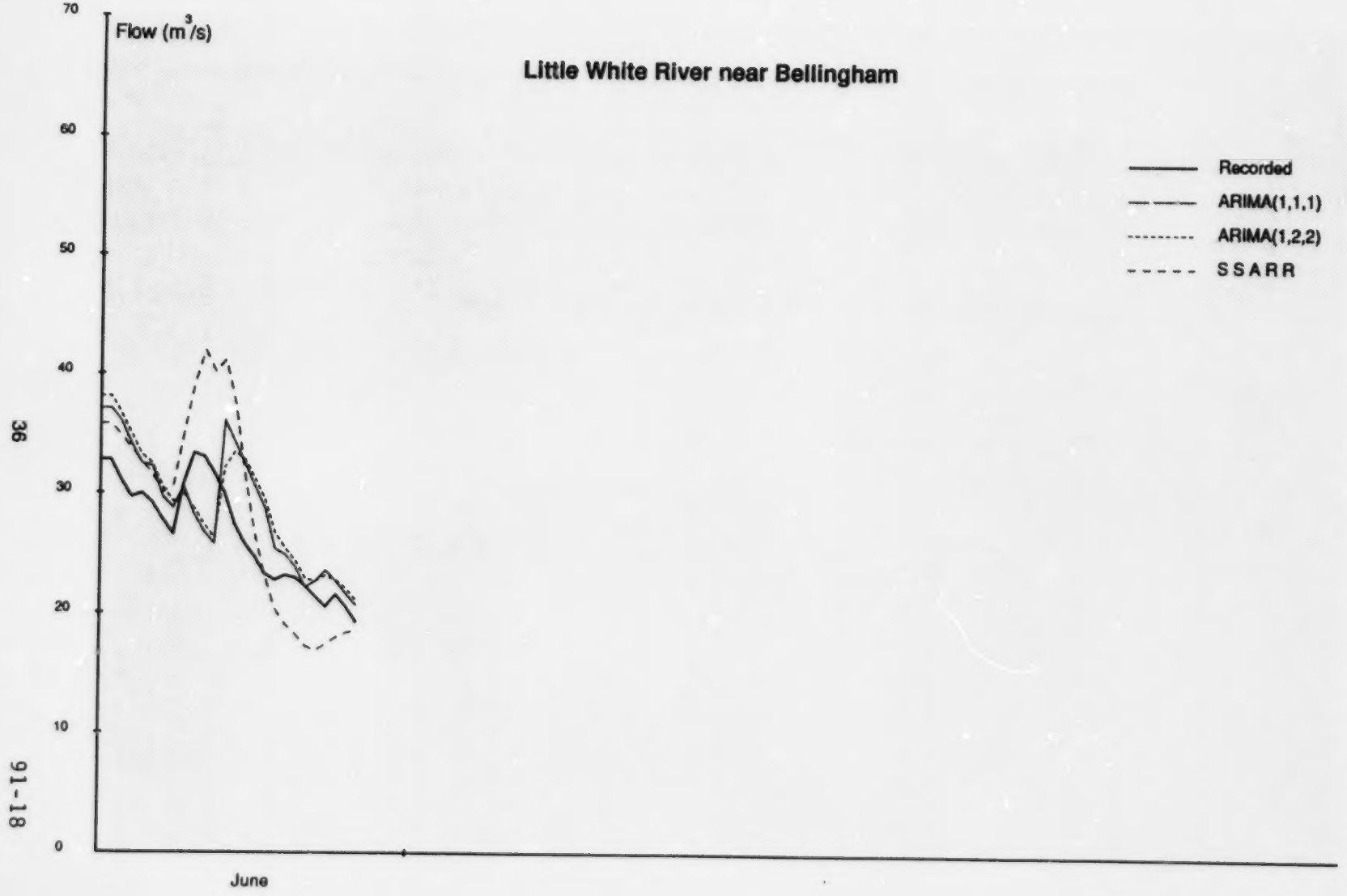

Figure 9.4 4-Days Ahead Forecast (1 June - 25 June 1978)

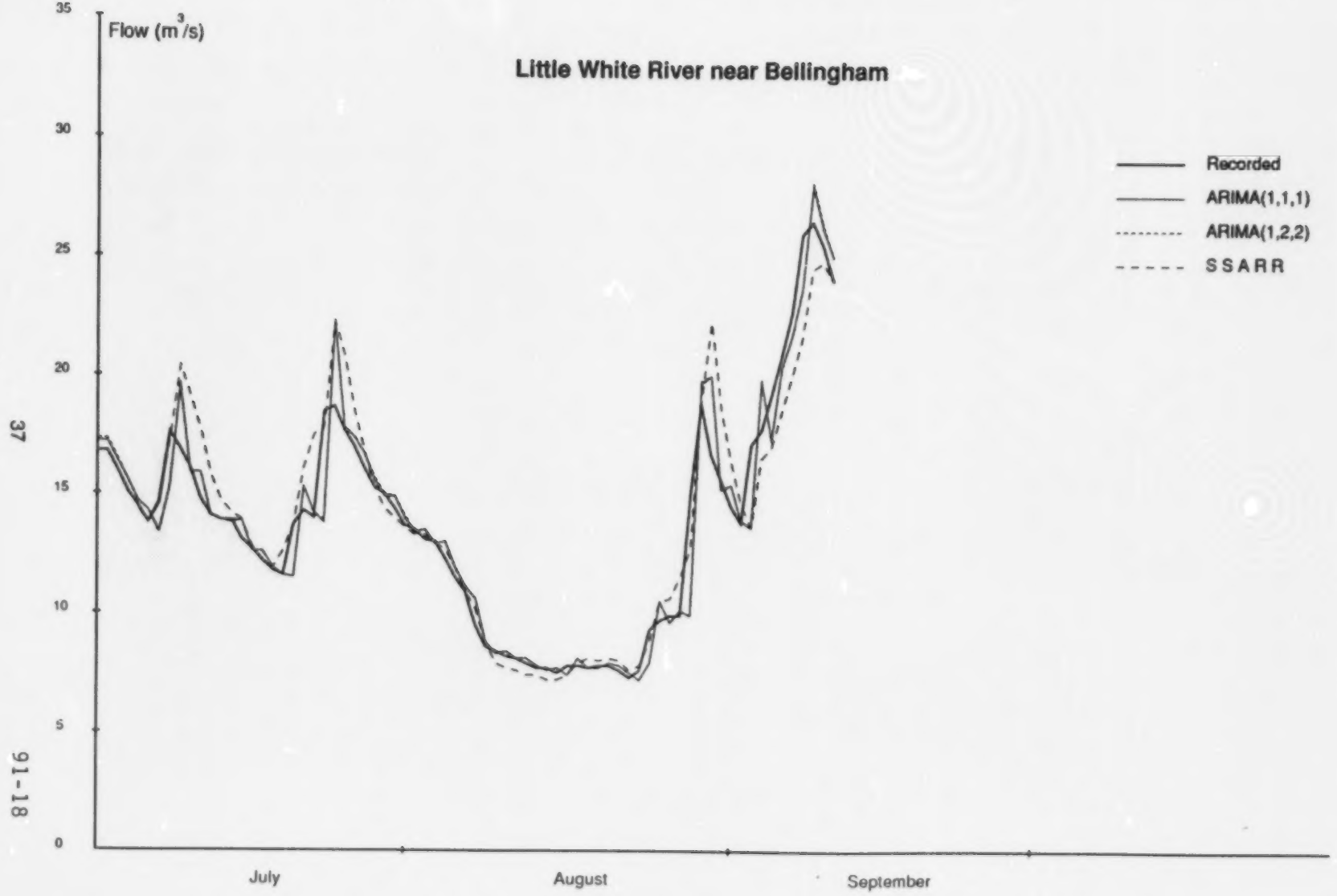

Figure 10.1 1-Day Ahead Forecast (1 July - 10 September 1978)

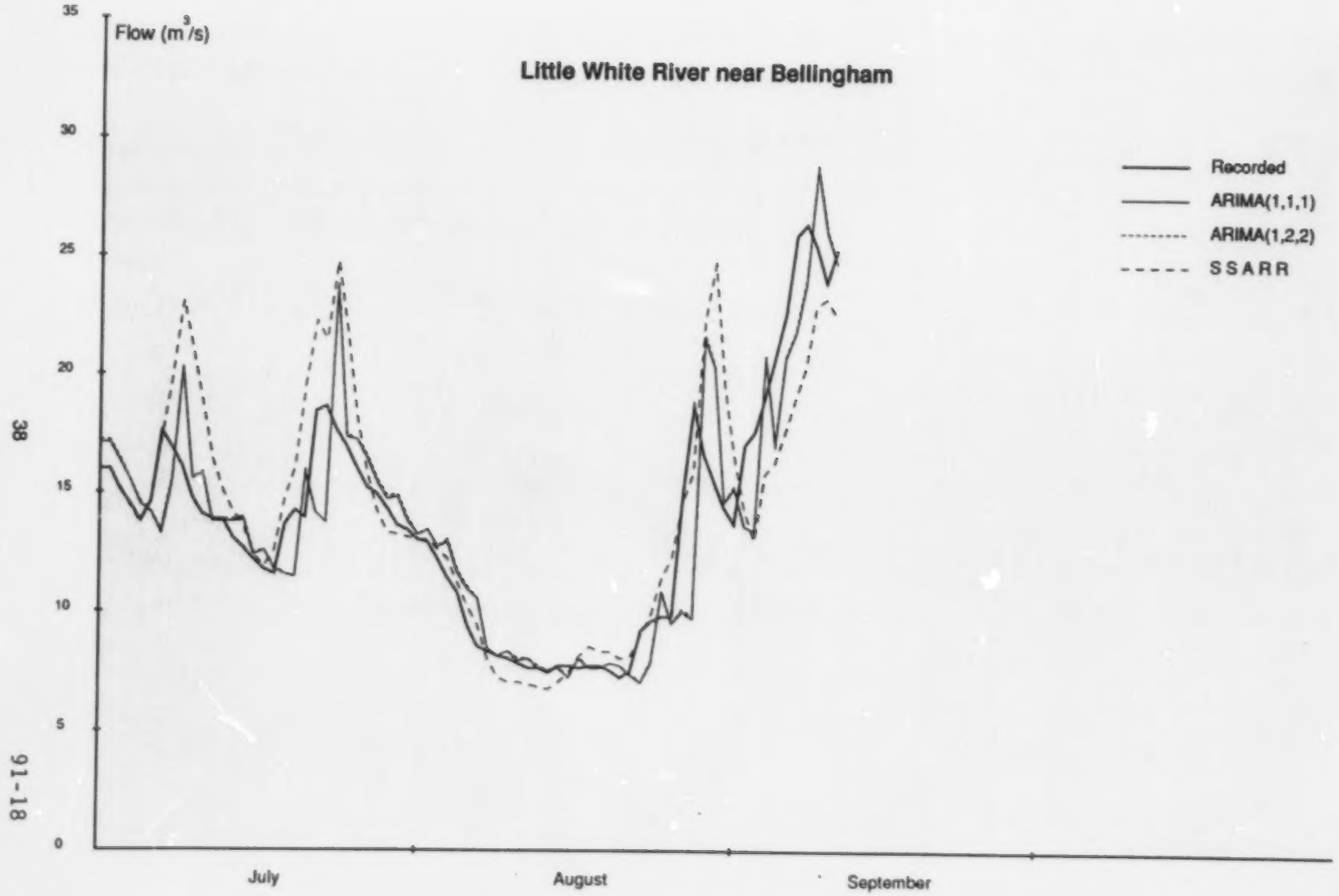

Figure 10.2 2-Days Ahead Forecast (1 July - 10 September 1978)

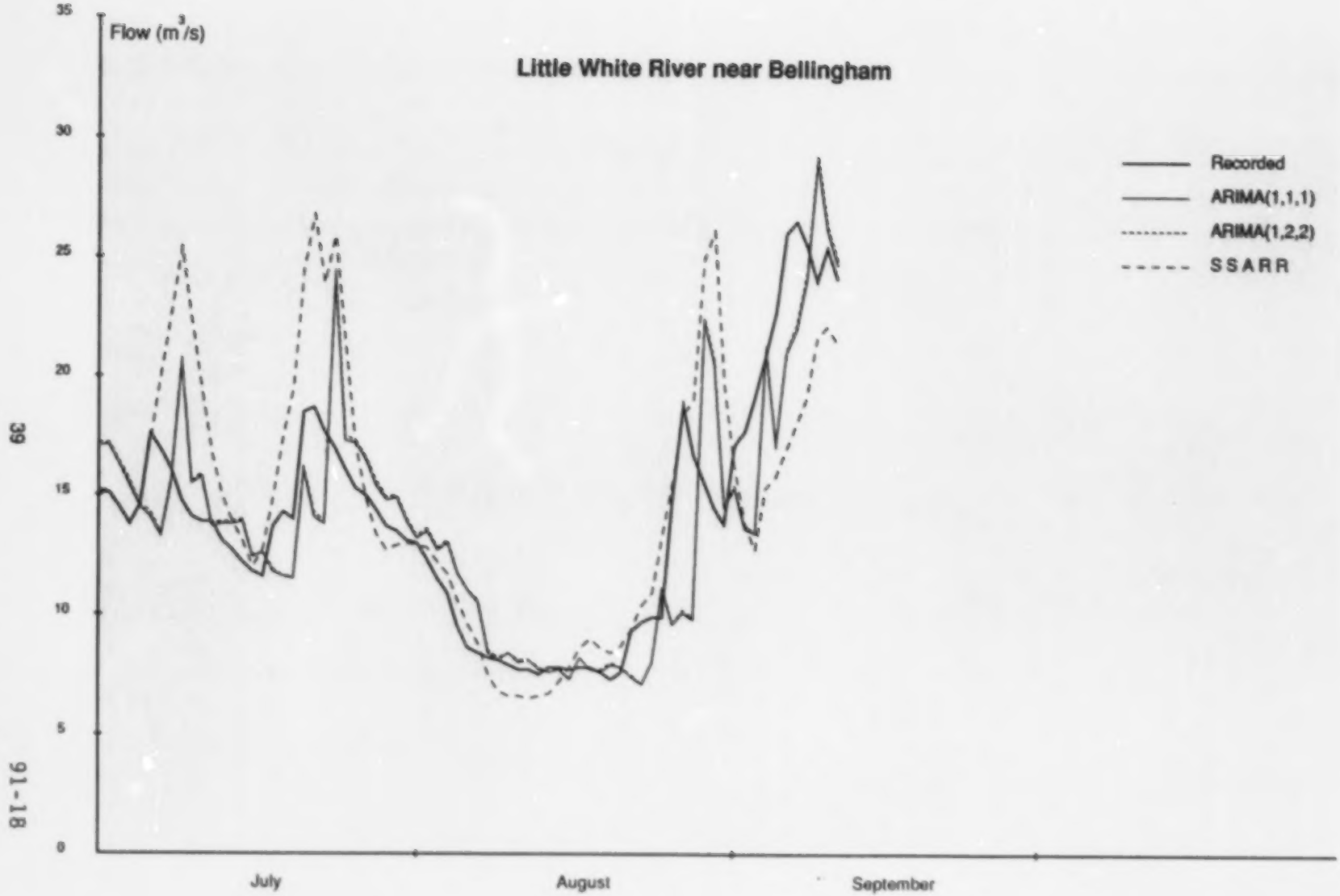

Figure 10.3 3-Days Ahead Forecast (1 July - 10 September 1978)

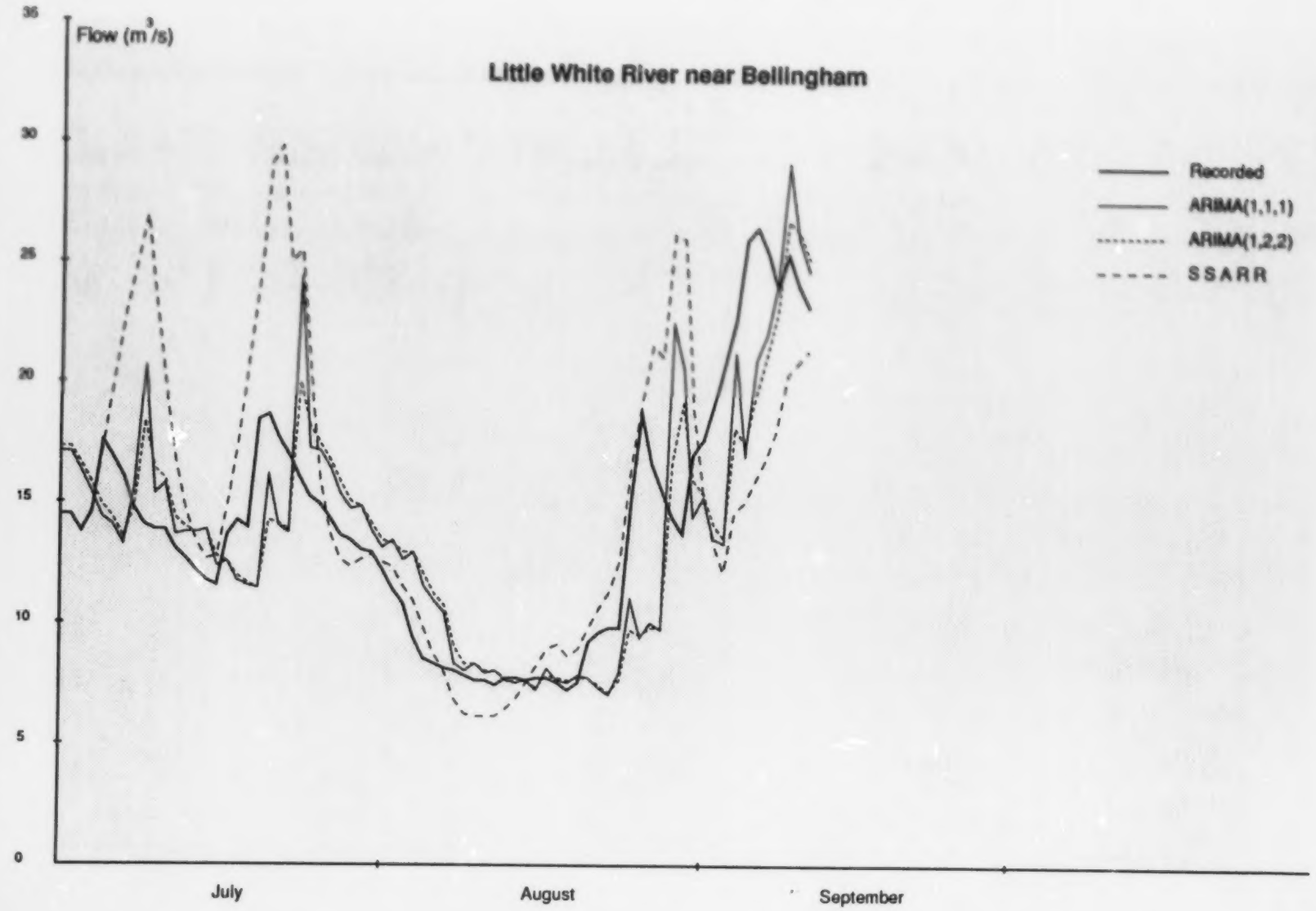

Figure 10.4 4-Days Ahead Forecast (1 July - 10 September 1978)

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91-118

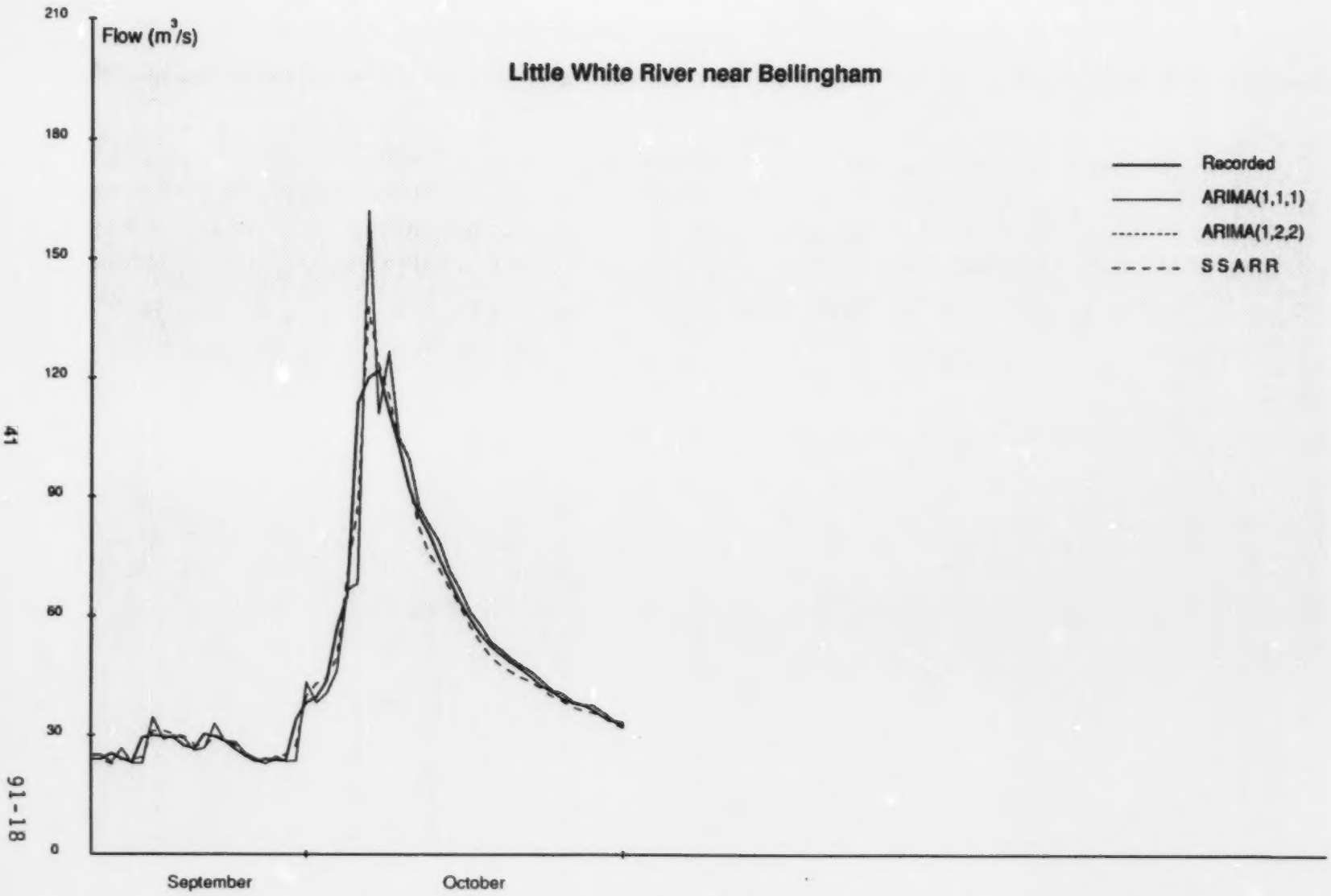


Figure 11.1 1-Day Ahead Forecast (10 September - 31 October 1978)

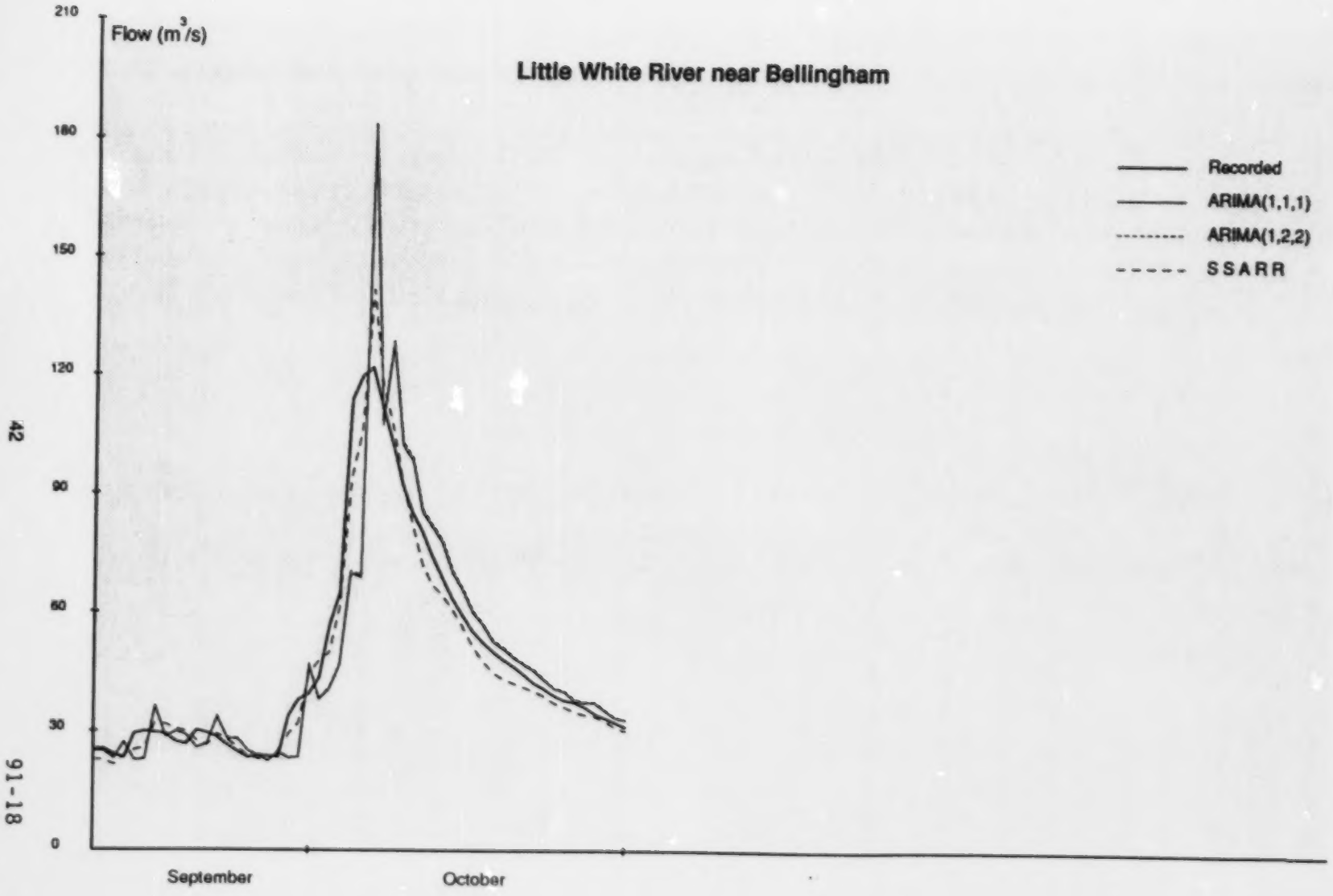


Figure 11.2 2-Days Ahead Forecast (10 September - 31 October 1978)

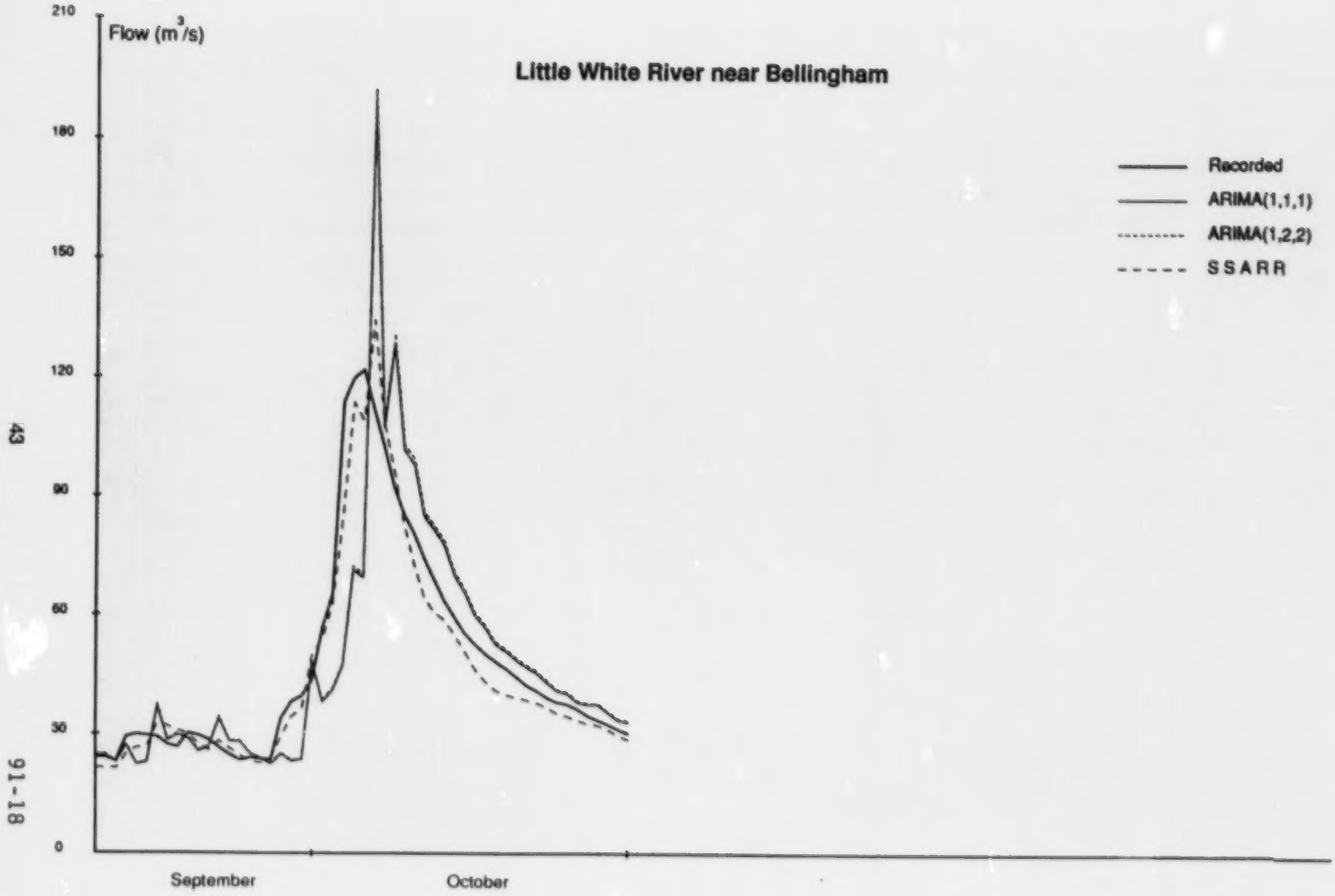


Figure 11.3 3-Days Ahead Forecast (10 September - 31 October 1978)

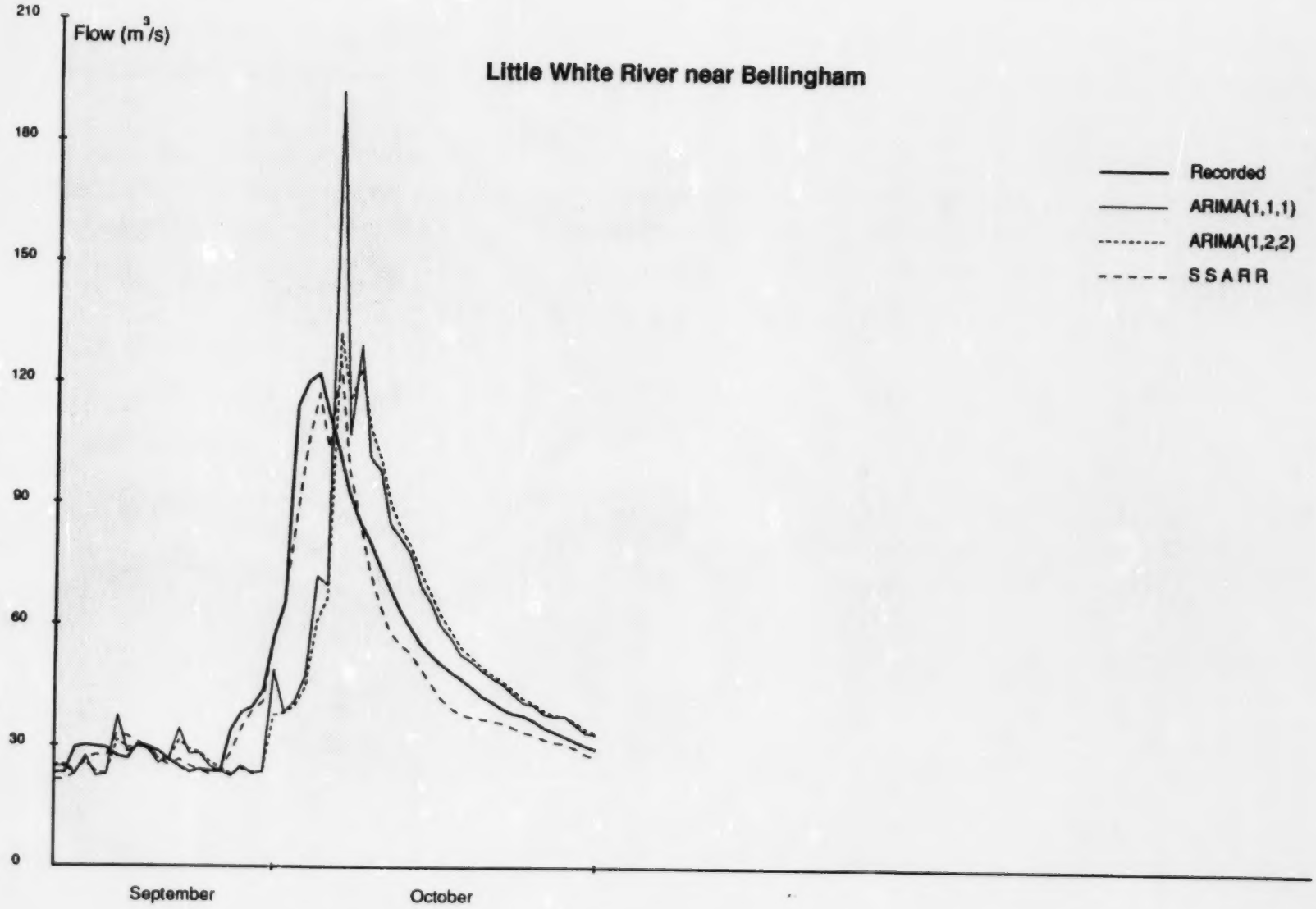


Figure 11.4 4-Days Ahead Forecast (10 September - 31 October 1978)

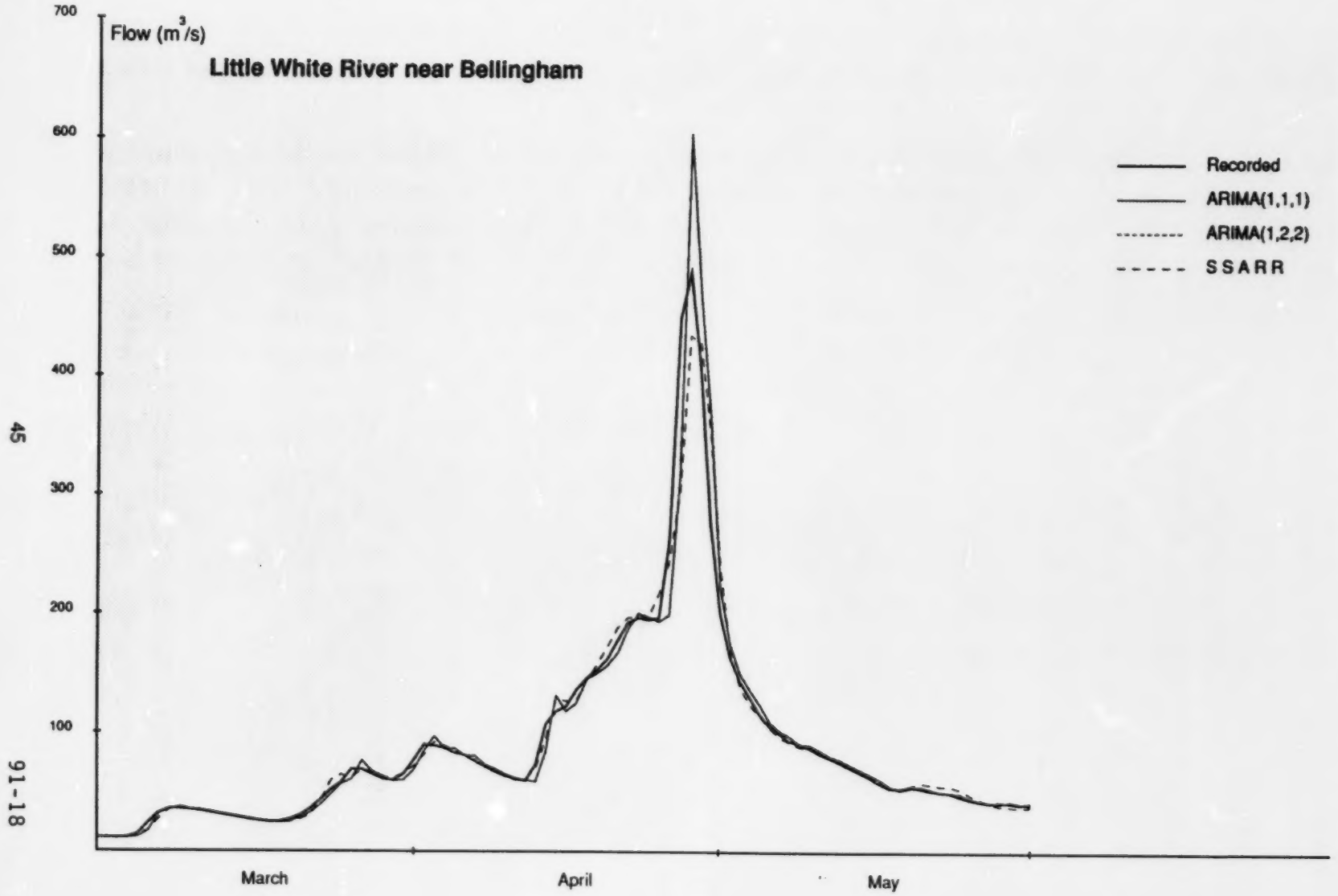


Figure 12.1 1-Day Ahead Forecast (1 March - 31 May 1979)

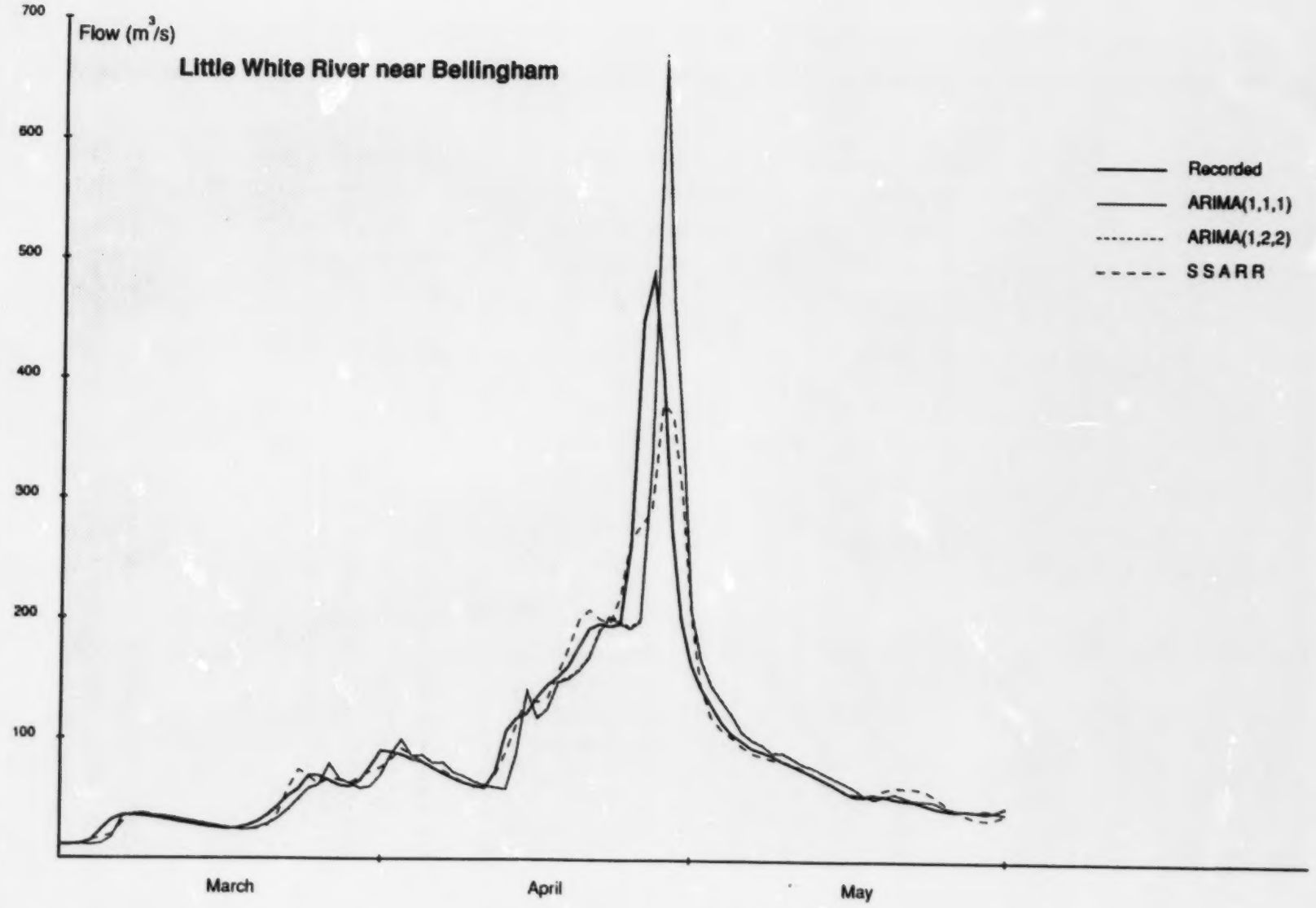


Figure 12.2 2-Days Ahead Forecast (1 March - 31 May 1979)

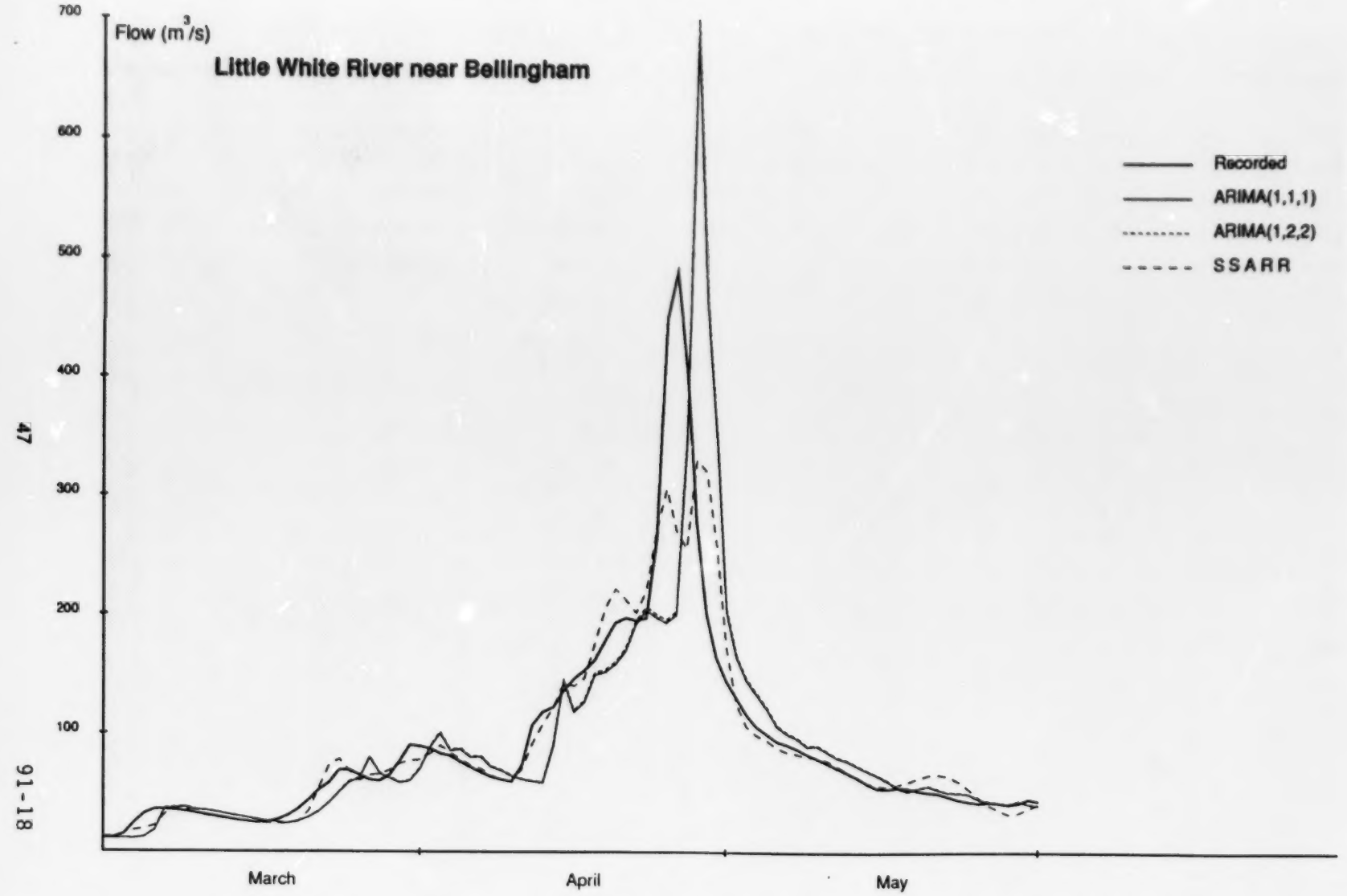


Figure 12.3 3-Days Ahead Forecast (1 March - 31 May 1979)

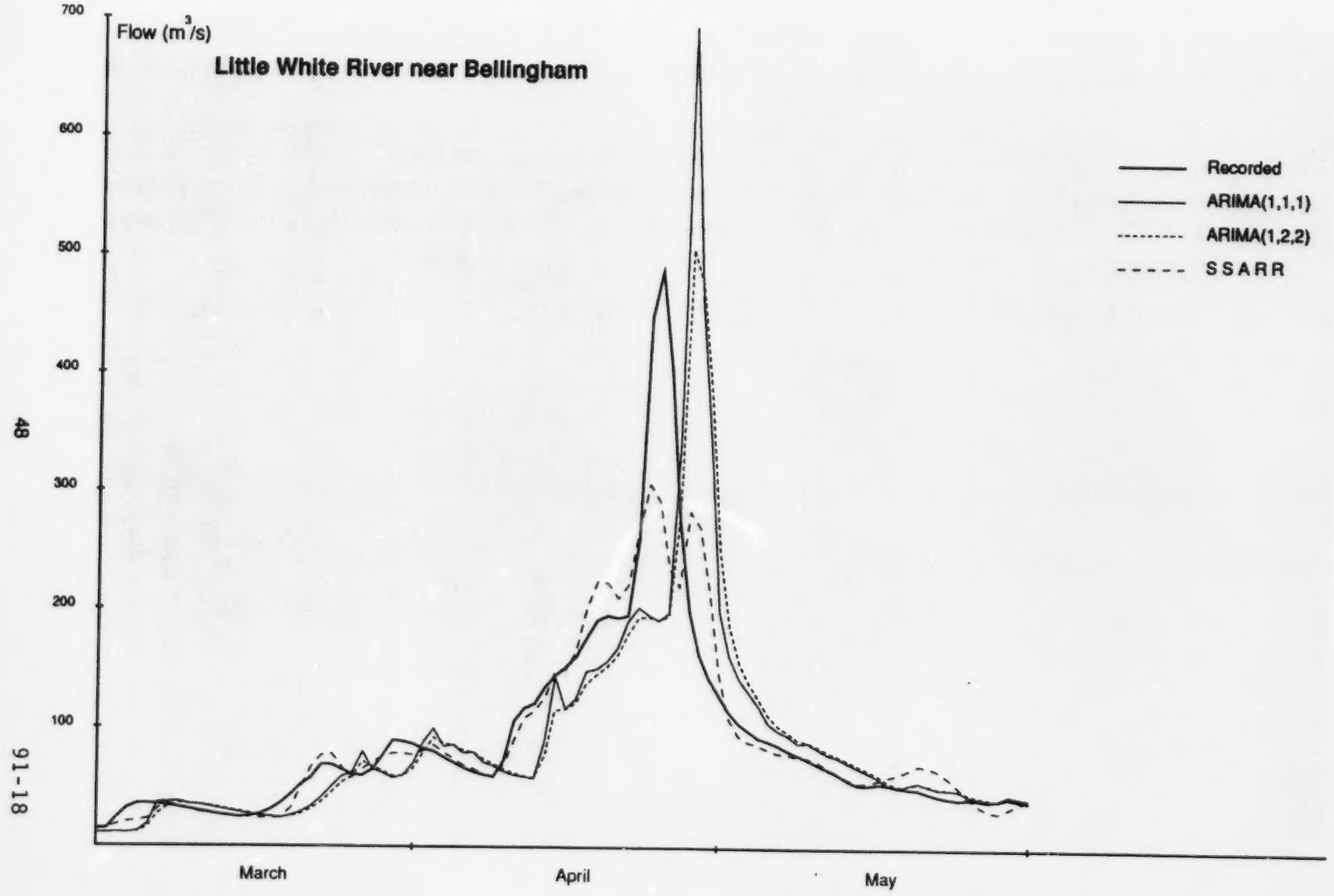


Figure 12.4 4-Days Ahead Forecast (1 March - 31 May 1979)

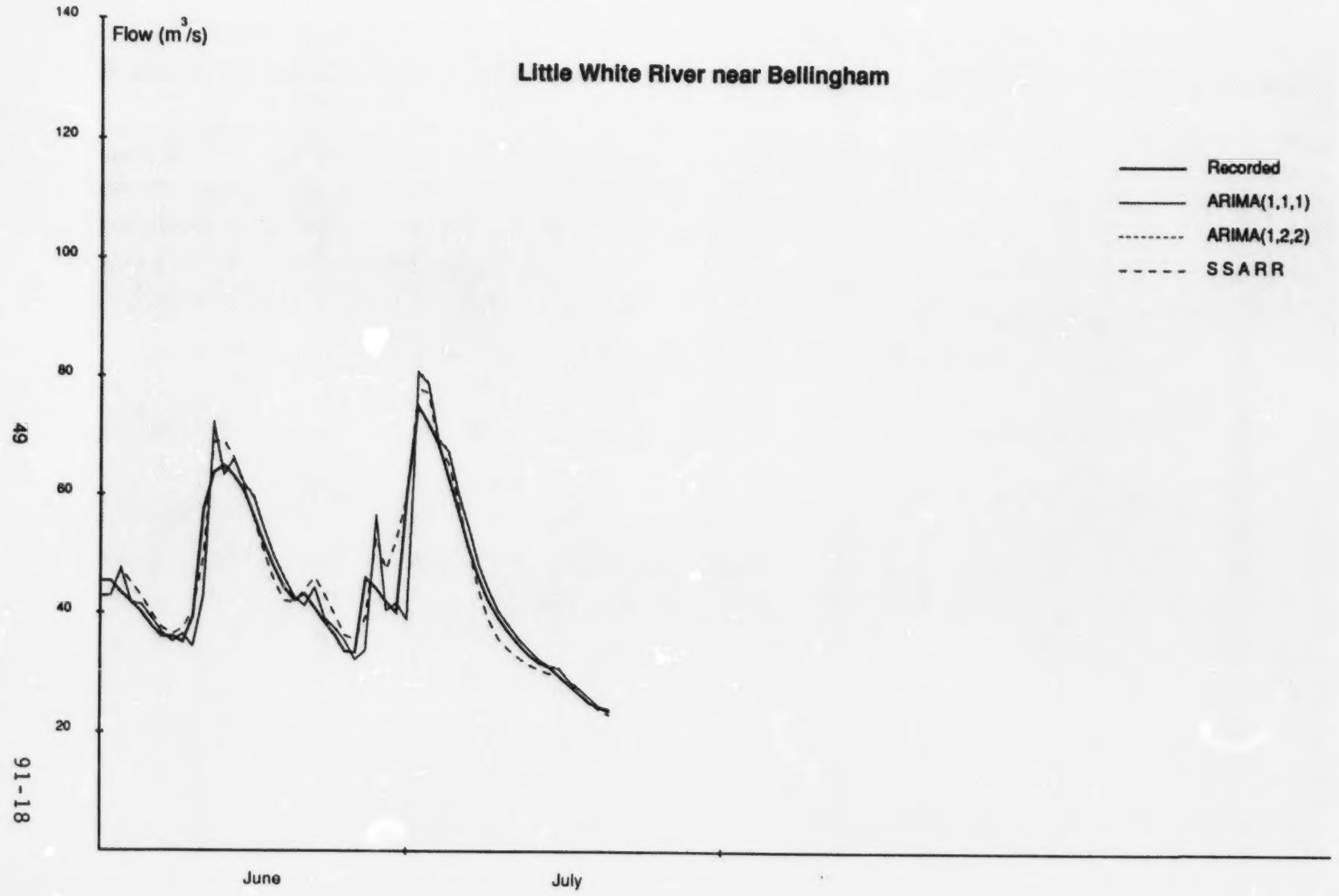


Figure 13.1 1-Day Ahead Forecast (1 June - 20 July 1979)

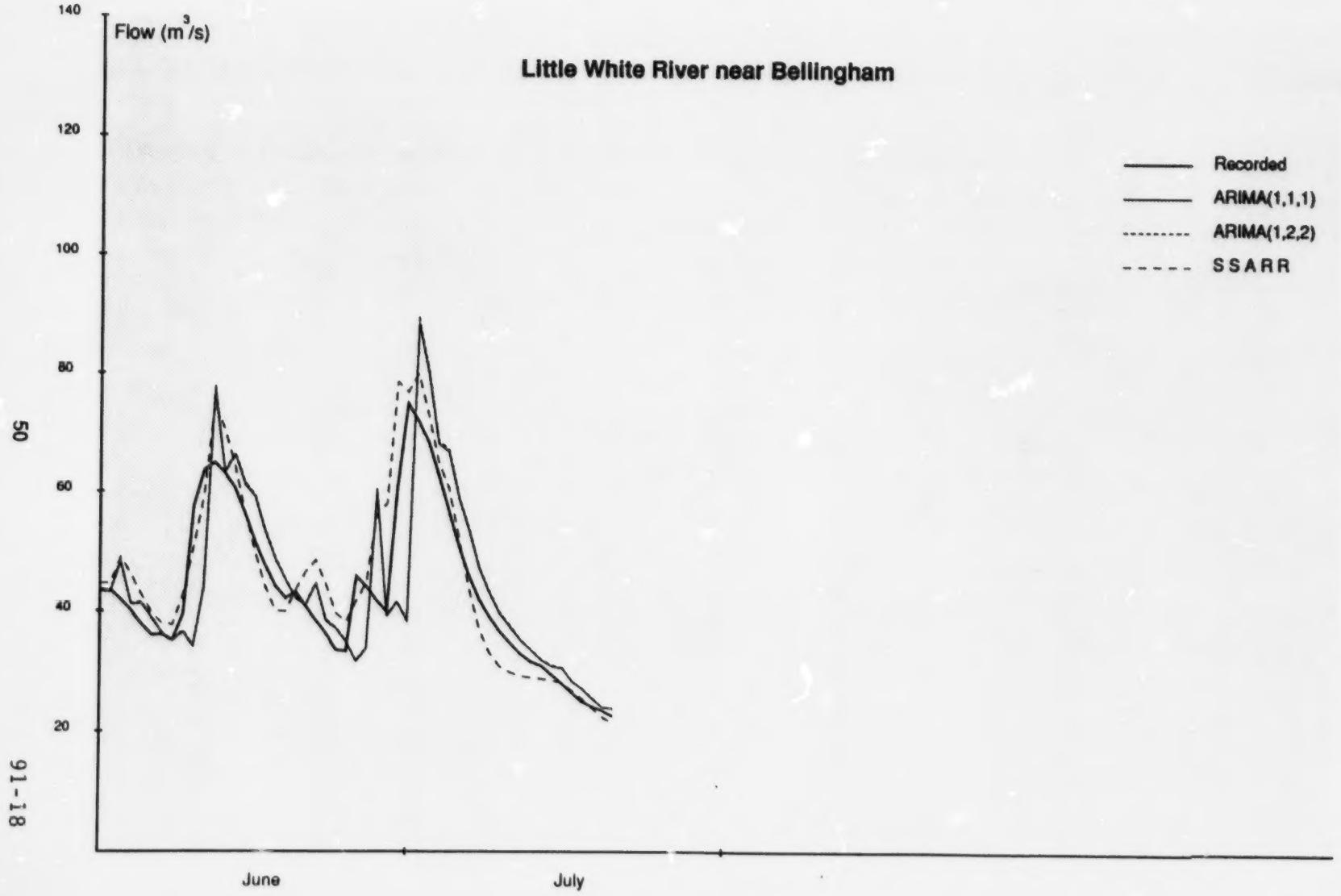


Figure 13.2 2-Days Ahead Forecast (1 June - 20 July 1979)

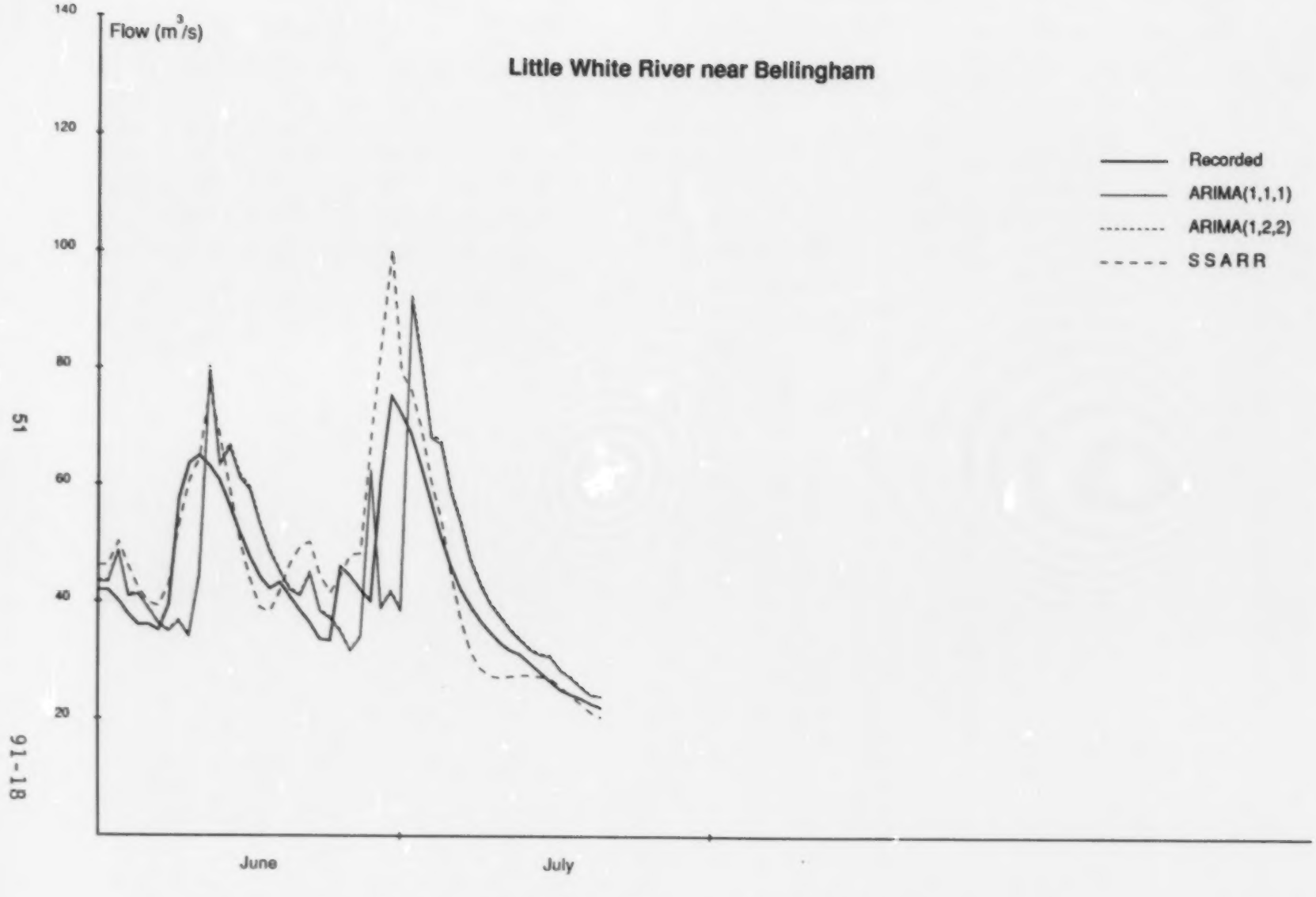


Figure 13.3 3-Days Ahead Forecast (1 June - 20 July 1979)

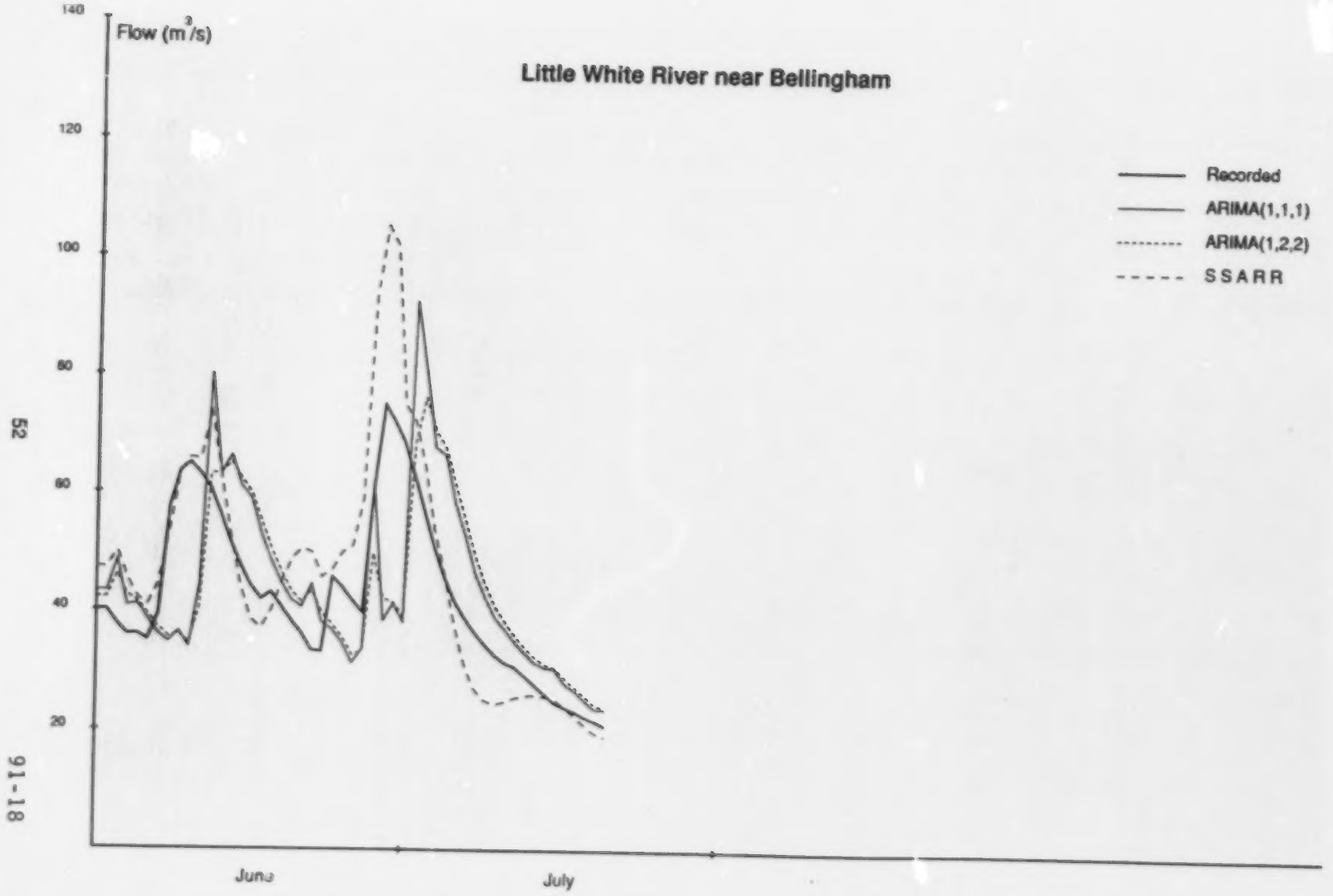


Figure 13.4 4-Days Ahead Forecast (1 June - 20 July 1979)

Table 1. Data Available

Streamflow Data	
Aubinadong River	Sep 1980 - Dec 1989
Little White River/ Boland	Sep 1980 - Dec 1989
Little White River/Bellingham	Jun 1942 - Dec 1989
Precipitation	
Elliot Lake Denison	Mar 1974 - May 1980
Mississagi Ontario Hydro	Aug 1970 - Oct 1989
Montreal Falls	Nov 1976 - Oct 1989
Biscotasing	Jan 1914 - Oct 1989
Blind River Hydro Centre	Jun 1982 - Oct 1989
Elliot Lake Stanleigh	Jun 1984 - Oct 1989
Maximum Temperature	
Elliot Lake Denison	Mar 1974 - May 1980
Mississagi Ontario Hydro	Sep 1976 - Oct 1989
Montreal Falls	Nov 1976 - Oct 1989
Biscotasing	Jan 1914 - Nov 1972
Blind River Hydro Centre	Jun 1982 - Oct 1989
Elliot Lake Stanleigh	Oct 1984 - Oct 1989
Snowpack	
Red Rock	1950 - 1990
Aubrey Falls	1950 - 1990
Chapleau	1950 - 1990
Biscotasing	1950 - 1990

Table 2

SSARR Performance Results

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 2/11/1975 to 31/12/1975							
1 day	19.79	8.68	20.24	9.33	.957	.900	.700
2 day	19.93	8.53	20.95	9.99	.907	.739	.500
3 day	20.07	8.38	21.72	10.64	.877	.577	.300
4 day	20.21	8.23	22.52	11.15	.842	.366	.100
Time interval 20/ 3/1976 to 30/ 6/1976							
1 day	58.15	48.23	57.54	47.67	.994	.988	.700
2 day	58.21	48.17	57.24	46.93	.976	.951	.500
3 day	58.25	48.13	57.12	46.17	.947	.895	.300
4 day	58.28	48.10	57.07	45.42	.915	.836	.100
Time interval 5/ 3/1977 to 31/ 5/1977							
1 day	42.65	30.66	43.07	31.38	.996	.991	.700
2 day	42.72	30.58	43.75	32.49	.986	.966	.500
3 day	42.82	30.49	44.56	33.90	.975	.929	.300
4 day	42.92	30.38	45.40	35.38	.965	.885	.100
Time interval 25/ 6/1977 to 25/ 7/1977							
1 day	9.70	1.68	9.86	2.24	.938	.717	.700
2 day	9.68	1.70	10.04	3.01	.894	-.022	.500
3 day	9.66	1.72	10.27	3.87	.870	-1.285	.300
4 day	9.64	1.74	10.52	4.72	.871	-2.889	.100
Time interval 1/ 9/1977 to 10/12/1977							
1 day	40.62	23.36	39.90	23.59	.982	.963	.700
2 day	40.90	23.12	39.43	23.38	.954	.902	.500
3 day	41.16	22.87	38.85	22.86	.928	.847	.300
4 day	41.43	22.62	38.18	22.03	.908	.799	.100
Time interval 1/ 4/1978 to 31/ 5/1978							
1 day	52.68	33.45	52.71	33.90	.996	.993	.700
2 day	53.11	33.09	53.34	34.33	.990	.977	.500
3 day	53.51	32.74	54.04	34.98	.982	.956	.300
4 day	53.88	32.40	54.77	35.64	.974	.933	.100

Table 2

SSARR Performance Results (cont'd)

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 1/ 6/1978 to 25/ 6/1978							
1 day	29.00	4.79	29.55	5.70	.978	.898	.700
2 day	28.28	4.63	29.38	6.61	.951	.620	.500
3 day	27.66	4.44	29.25	7.59	.939	.161	.300
4 day	27.07	4.36	29.12	8.53	.933	-.403	.100
Time interval 1/ 7/1978 to 10/ 9/1978							
1 day	13.65	4.58	13.93	4.57	.939	.875	.700
2 day	13.74	4.71	14.36	4.97	.826	.612	.500
3 day	13.86	4.90	14.82	5.51	.711	.295	.300
4 day	13.97	5.03	15.28	6.08	.609	-.055	.100
Time interval 10/ 9/1978 to 31/10/1978							
1 day	48.20	27.46	47.37	27.66	.984	.967	.700
2 day	48.34	27.36	46.64	27.31	.981	.959	.500
3 day	48.48	27.26	45.91	26.70	.973	.938	.300
4 day	48.58	27.19	45.21	26.04	.973	.930	.100
Time interval 1/ 3/1979 to 31/ 5/1979							
1 day	90.12	85.85	89.59	81.79	.974	.949	.700
2 day	90.45	85.60	89.32	77.35	.928	.861	.500
3 day	90.82	85.33	89.15	74.09	.903	.814	.300
4 day	91.18	85.07	89.05	71.71	.906	.816	.100
Time interval 1/ 6/1979 to 20/ 7/1979							
1 day	44.52	12.56	45.35	13.39	.965	.916	.700
2 day	44.16	12.89	46.01	15.11	.927	.778	.500
3 day	43.70	13.23	46.72	17.52	.906	.594	.300
4 day	43.27	13.58	47.34	19.91	.903	.410	.100

Table 3

ARIMA(1,1,1) Performance Results

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 2/11/1975 to 31/12/1975							
1 day	19.80	8.67	19.89	9.31	.946	.877	.700
2 day	19.94	8.53	20.01	9.64	.838	.615	.500
3 day	20.08	8.38	20.05	9.78	.764	.421	.300
4 day	20.22	8.22	20.06	9.82	.659	.145	.100
Time interval 20/03/1976 to 30/06/1976							
1 day	58.15	48.23	58.28	48.84	.995	.990	.700
2 day	58.21	48.17	58.37	49.17	.973	.944	.500
3 day	58.25	48.13	58.41	49.30	.930	.856	.300
4 day	58.28	48.10	58.42	49.34	.875	.742	.100
Time interval 5/03/1977 to 31/05/1977							
1 day	42.66	30.65	42.79	30.95	.995	.991	.700
2 day	42.73	30.58	42.90	31.10	.975	.949	.500
3 day	42.83	30.48	42.94	31.17	.938	.872	.300
4 day	42.93	30.38	42.96	31.19	.886	.766	.100
Time interval 25/06/1977 to 25/07/1977							
1 day	9.72	1.66	9.74	1.79	.922	.827	.700
2 day	9.70	1.68	9.74	1.86	.824	.598	.500
3 day	9.67	1.71	9.74	1.89	.674	.264	.300
4 day	9.65	1.72	9.74	1.90	.560	.018	.100
Time interval 1/09/1977 to 10/12/1977							
1 day	40.56	23.26	40.64	24.15	.976	.949	.700
2 day	40.84	23.04	40.83	24.59	.922	.828	.500
3 day	41.11	22.81	40.90	24.77	.861	.690	.300
4 day	41.39	22.57	40.93	24.84	.793	.534	.100
Time interval 1/04 3/1978 to 31/05/1978							
1 day	52.68	33.45	52.59	34.02	.994	.987	.700
2 day	53.11	33.09	52.75	34.18	.969	.934	.500
3 day	53.51	32.75	52.81	34.25	.922	.835	.300
4 day	53.88	32.41	52.83	34.27	.859	.697	.100

Table 3

ARIMA(1,1,1) Performance Results (cont'd)

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 1/06/1978 to 25/06/1978							
1 day	29.01	4.80	29.45	5.12	.970	.924	.700
2 day	28.28	4.63	29.34	5.19	.889	.684	.500
3 day	27.66	4.44	29.31	5.21	.795	.352	.300
4 day	27.07	4.36	29.30	5.22	.721	.031	.100
Time interval 1/07/1978 to 10/09/1978							
1 day	13.66	4.56	13.66	4.69	.957	.911	.700
2 day	13.75	4.70	13.71	4.85	.876	.742	.500
3 day	13.87	4.88	13.73	4.91	.816	.629	.300
4 day	13.98	5.02	13.73	4.94	.755	.516	.100
Time interval 10/09/1978 to 31/10/1978							
1 day	48.20	27.46	48.55	29.57	.948	.881	.700
2 day	48.34	27.37	48.83	30.96	.887	.728	.500
3 day	48.48	27.26	48.94	31.53	.785	.478	.300
4 day	48.58	27.19	48.98	31.73	.680	.226	.100
Time interval 1/03/1979 to 31/05/1979							
1 day	90.12	85.87	90.93	91.94	.969	.927	.700
2 day	90.45	85.63	91.55	95.54	.855	.664	.500
3 day	90.82	85.35	91.79	96.96	.711	.324	.300
4 day	91.18	85.09	91.87	97.46	.605	.074	.100
Time interval 1/06/1979 to 20/07/1979							
1 day	44.53	12.56	44.94	13.64	.927	.834	.700
2 day	44.16	12.89	45.03	14.47	.766	.455	.500
3 day	43.71	13.24	45.07	14.80	.603	.087	.300
4 day	43.28	13.58	45.08	14.91	.487	-.153	.100

Table 4

ARIMA(1,2,2) Performance Results

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 2/11/1975 to 31/12/1975							
1 day	19.80	8.67	20.03	9.39	.945	.874	.700
2 day	19.94	8.53	20.40	9.86	.837	.597	.500
3 day	20.08	8.38	20.72	10.14	.764	.377	.300
4 day	20.22	8.22	19.49	8.82	.638	.209	.100
Time interval 20/03/1976 to 30/06/1976							
1 day	58.15	48.23	58.67	49.22	.995	.990	.700
2 day	58.21	48.17	59.43	50.19	.973	.941	.500
3 day	58.25	48.13	60.23	51.05	.930	.846	.300
4 day	58.28	48.10	57.46	47.79	.850	.702	.100
Time interval 5/03/1977 to 31/05/1977							
1 day	42.66	30.65	42.98	31.11	.995	.990	.700
2 day	42.73	30.58	43.41	31.53	.975	.948	.500
3 day	42.83	30.48	43.82	31.90	.938	.866	.300
4 day	42.93	30.38	42.32	30.51	.862	.722	.100
Time interval 25/06/1977 to 25/07/1977							
1 day	9.72	1.66	9.77	1.79	.922	.825	.700
2 day	9.70	1.68	9.81	1.88	.824	.588	.500
3 day	9.67	1.71	9.86	1.92	.674	.236	.300
4 day	9.65	1.72	9.70	1.67	.538	.102	.100
Time interval 1/09/1977 to 10/12/1977							
1 day	40.56	23.26	40.78	24.24	.976	.948	.700
2 day	40.84	23.04	41.22	24.86	.921	.824	.500
3 day	41.11	22.81	41.56	25.23	.860	.679	.300
4 day	41.39	22.57	40.14	23.51	.793	.564	.100
Time interval 1/04/1978 to 31/05/1978							
1 day	52.68	33.45	52.75	34.14	.994	.987	.700
2 day	53.11	33.09	53.18	34.51	.969	.933	.500
3 day	53.51	32.75	53.54	34.80	.922	.831	.300
4 day	53.88	32.41	52.07	33.64	.829	.640	.100

Table 4

ARIMA(1,2,2) Performance Results (cont'd)

Forecast for	Observed Mean	Observed STD	Predicted Mean	Predicted STD	Correlation Coeff.	Nash Coefficient Computed	Nash Coefficient Required
Time interval 1/06/1978 to 25/06/1978							
1 day	29.01	4.80	29.51	5.14	.970	.921	.700
2 day	28.28	4.63	29.52	5.23	.889	.660	.500
3 day	27.66	4.44	29.62	5.29	.795	.283	.300
4 day	27.07	4.36	29.51	5.02	.727	.033	.100
Time interval 1/07/1978 to 10/09/1978							
1 day	13.66	4.56	13.68	4.70	.957	.910	.700
2 day	13.75	4.70	13.77	4.89	.875	.739	.500
3 day	13.87	4.88	13.83	4.97	.816	.625	.300
4 day	13.98	5.02	13.56	4.46	.769	.569	.100
Time interval 10/09/1978 to 31/10/1978							
1 day	48.20	27.46	48.67	29.67	.948	.880	.700
2 day	48.34	27.37	49.15	31.26	.887	.721	.500
3 day	48.48	27.26	49.49	32.04	.785	.462	.300
4 day	48.58	27.19	48.01	27.93	.670	.322	.100
Time interval 1/03/1979 to 31/05/1979							
1 day	90.12	85.87	91.17	92.30	.968	.926	.700
2 day	90.45	85.63	92.20	96.53	.855	.656	.500
3 day	90.82	85.35	92.90	98.65	.710	.304	.300
4 day	91.18	85.09	89.76	87.26	.626	.231	.100
Time interval 1/06/1979 to 20/07/1979							
1 day	44.53	12.56	45.01	13.68	.927	.832	.700
2 day	44.16	12.89	45.23	14.58	.766	.447	.500
3 day	43.71	13.24	45.41	14.98	.603	.067	.300
4 day	43.28	13.58	44.73	12.60	.441	-.054	.100

Table 5

Performance Comparison (Nash Coefficients)

Forecast for	S S A R R	ARIMA (1,1,1)	ARIMA (1,2,2)	Required
Time interval 2/11/1975 to 31/12/1975				
1 day	0.900	0.877	0.874	0.700
2 day	0.739	0.615	0.597	0.500
3 day	0.577	0.421	0.377	0.300
4 day	0.366	0.145	0.209	0.100
Time interval 20/03/1976 to 30/06/1975				
1 day	0.988	0.990	0.990	0.700
2 day	0.951	0.944	0.941	0.500
3 day	0.895	0.856	0.846	0.300
4 day	0.836	0.742	0.702	0.100
Time interval 5/03/1977 to 31/05/1977				
1 day	0.991	0.991	0.990	0.700
2 day	0.966	0.949	0.948	0.500
3 day	0.929	0.872	0.866	0.300
4 day	0.885	0.766	0.722	0.100
Time interval 25/06/1977 to 25/07/1977				
1 day	0.717	0.827	0.825	0.700
2 day	-0.022	0.598	0.588	0.500
3 day	-1.285	0.264	0.236	0.300
4 day	-2.889	0.018	0.102	0.100
Time interval 1/09/1977 to 10/12/1977				
1 day	0.963	0.949	0.948	0.700
2 day	0.902	0.828	0.842	0.500
3 day	0.847	0.690	0.679	0.300
4 day	0.799	0.534	0.564	0.100
Time interval 1/04/1978 to 31/05/1978				
1 day	0.993	0.987	0.987	0.700
2 day	0.977	0.934	0.933	0.500
3 day	0.956	0.835	0.831	0.300
4 day	0.933	0.697	0.640	0.100
Time interval 1/06/1978 to 25/06/1978				
1 day	0.898	0.924	0.921	0.700
2 day	0.620	0.684	0.660	0.500
3 day	0.161	0.352	0.283	0.300
4 day	-0.403	0.031	0.033	0.100
Time interval 1/07/1978 to 10/09/1978				
1 day	0.875	0.911	0.910	0.700
2 day	0.612	0.742	0.739	0.500
3 day	0.295	0.629	0.625	0.300
4 day	-0.055	0.516	0.569	0.100

Table 5

Performance Comparison (Nash Coefficients) (cont'd)

Forecast for	S S A R R	ARIMA (1,1,1)	ARIMA (1,2,2)	Required
Time interval 10/09/1978 to 31/10/1978				
1 day	0.967	0.881	0.880	0.700
2 day	0.959	0.728	0.721	0.500
3 day	0.938	0.478	0.462	0.300
4 day	0.930	0.226	0.322	0.100
Time interval 1/03/1979 to 31/05/1979				
1 day	0.949	0.927	0.926	0.700
2 day	0.861	0.664	0.656	0.500
3 day	0.814	0.324	0.304	0.300
4 day	0.816	0.074	0.231	0.100
Time interval 1/06/1979 to 20/07/1979				
1 day	0.916	0.834	0.832	0.700
2 day	0.778	0.455	0.447	0.500
3 day	0.594	0.087	0.067	0.300
4 day	0.410	-0.153	-0.054	0.100

APPENDIX A

SSARR Calibration

Table A1 - SSARR Parameters
Table A2 - SSARR Calibration Performance Results

Figure A1 - Calibration Results (November 1979 - October 1981)
Figure A2 - Calibration Results (November 1981 - October 1983)
Figure A3 - Calibration Results (November 1983 - October 1985)
Figure A4 - Calibration Results (November 1985 - October 1987)
Figure A5 - Calibration Results (November 1987 - October 1989)

Table A1

SSARR Calibration Results

```
ZC1 LITW,LITTLE WHITE RIVER NEAR BELLINGHAM
ZC2 LITW,1960,1,4,17,6,26,2,200,2,1500,60,3.0,.25,30.0,0.05
ZC3 LITW,ELP3,ATI1,.98,.84,.20,.03,.95,500,3.0
ZC4 LITW,SMI6,BII2,SSS2,EKE1,ETP2,DKE1,ETM2
ZC5 LITW,INT1,1.2,3.2,.045,.084,GRM3,ELE1,7.0,20,0.6
ZC6 LITW,MPR3,    BELI
ZCH LITW,4,MIST,100
ZCH LITW,3,MISP,97
ZCA LITW 100
ZCP LITW 320,0,420,65 550,100
ZCT ELP3 2  100,100 300,100  600,100
ZCT ATI1 3  0,.02,.06  20,.04,.06  40,.06,.06  60,.08,.06 80,.1,.06
ZCT2 ATI1  100,.12,.06 120,.14,.06 140,.15,.06  180,.15,.06  999,.15,.06
ZCT SMI6 2  0,20 5,26 8,32 10,50 12,70 15,85 20,90 999,100
ZCT BII2 2  0,90 .1,70 .2,60 .4,55 .6,50  1,45 1.5,35 999,35
ZCT SSS2 2  0,0 .02,.002  .03,.006  .04,.012  .06,.024
ZCT2 SSS2    .12,.06  1.2,.72  99,60
ZCT EKE1 2  0,100 .01,90 .1,70 0.5,60 1.0,20 2.0,10 999,0
ZCT ETP2 2 -20,0.05  0,0.08  10,.2  15,.25  20,.3  30,.4 999,.4
ZCT DKE1 2  0,0 1,10 2.5,30 5,70 7.5,90 10,95 15,100 999,100
ZCT ETM2 2  1,45  2,45  3,45  4,50  5,50 6,80 7,110  8,110  9,100
ZCT2 ETM2   10,100  11,90  12,50  13,45
ZCT GRM3 2  1,.03 2,.04 3,.05 5,.05 9,.05 10,.05 11,.05 12,.04 13,.03
ZCT ELE1 2  100,100  900,100
ZCT MPR3 2  1,90  3,90 4,95 5,115 10,115  13,90
ZCT INT1 2  1,.04  5,.04  6,.06  7,.14  10,.14  11,.08  13,.04
```

Table A2

SSARR Calibration Performance Results

	1979 Nov	Dec	Jan	Feb	Mar	1980 Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	77	70	16	13	20	243	44	70	48	36	87	66	243
Observed Maximum Flow	96	78	26	17	15	116	68	32	21	12	11	18	116
Day Computed Max Occurred	29	1	1	1	31	11	1	17	20	17	27	1	Apr11
Day Observed Max Occurred	28	1	18	1	31	10	1	16	1	28	25	26	Apr10
Computed Mean Flow	50	31	14	12	12	113	32	39	37	26	39	29	36
Observed Mean Flow	66	32	19	14	11	71	44	25	15	10	9	12	27
Computed Volume, (cm)	6.58	4.17	1.89	1.58	1.68	14.95	4.34	5.11	5.08	3.55	5.13	4.03	58.15
Observed Volume, (cm)	8.73	4.35	2.61	1.79	1.55	9.35	6.00	3.24	1.98	1.30	1.18	1.61	43.73

	1980 Nov	Dec	Jan	Feb	Mar	1981 Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	22	10	8	10	35	212	50	55	44	24	20	37	212
Observed Maximum Flow	14	10	8	28	51	206	41	74	57	16	14	31	206
Day Computed Max Occurred	1	1	1	28	31	6	6	18	2	9	13	23	Apr 6
Day Observed Max Occurred	1	8	1	25	31	6	1	26	1	5	10	21	Apr 6
Computed Mean Flow	14	9	7	7	11	117	31	36	21	15	13	21	25
Observed Mean Flow	9	9	7	12	19	94	30	46	27	11	10	19	24
Computed Volume, (cm)	1.85	1.20	.95	.84	1.56	15.42	4.26	4.77	2.82	2.02	1.75	2.92	40.41
Observed Volume, (cm)	1.17	1.16	.97	1.43	2.52	12.47	4.16	6.03	3.64	1.52	1.32	2.59	39.04

	1981 Nov	Dec	Jan	Feb	Mar	1982 Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	20	12	6	5	6	82	186	25	20	14	28	38	186
Observed Maximum Flow	25	19	11	10	23	180	162	33	16	9	24	85	180
Day Computed Max Occurred	1	6	1	28	31	30	6	4	20	28	28	24	May 6
Day Observed Max Occurred	1	3	3	1	31	27	1	2	17	4	27	23	Apr27
Computed Mean Flow	11	9	5	5	5	22	89	17	12	10	21	25	19
Observed Mean Flow	20	14	11	9	13	71	75	21	12	7	18	42	26
Computed Volume, (cm)	1.42	1.20	.73	.62	.69	2.92	12.19	2.18	1.70	1.41	2.77	3.44	31.34
Observed Volume, (cm)	2.65	1.92	1.43	1.11	1.81	9.38	10.24	2.80	1.64	1.01	2.32	5.70	42.09

	1982 Nov	Dec	Jan	Feb	Mar	1983 Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	51	64	20	10	36	226	83	85	17	30	29	53	226
Observed Maximum Flow	56	76	72	25	54	224	159	172	24	11	9	37	224
Day Computed Max Occurred	23	8	1	1	13	16	31	1	6	31	1	18	Apr16
Day Observed Max Occurred	21	31	1	1	10	16	31	1	1	4	21	17	Apr16
Computed Mean Flow	35	32	14	10	24	89	58	41	14	17	21	30	32
Observed Mean Flow	43	46	38	21	32	83	71	60	16	9	6	19	37
Computed Volume, (cm)	4.59	4.35	1.86	1.23	3.33	11.78	7.93	5.46	1.91	2.38	2.81	4.11	51.79
Observed Volume, (cm)	5.68	6.31	5.24	2.56	4.34	10.96	9.73	7.91	2.14	1.20	.82	2.64	59.55

Table A2

SSARR Calibration Performance Results (cont'd)

	1983 Nov	Dec	Jan	Feb	Mar	Apr	1984 May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	46	32	10	8	30	148	46	43	44	20	40	52	148
Observed Maximum Flow	40	29	14	21	28	105	57	52	47	15	34	65	105
Day Computed Max Occurred	27	1	1	1	31	14	4	30	1	31	16	31	Apr14
Day Observed Max Occurred	25	1	1	20	31	18	2	29	1	28	25	31	Apr18
Computed Mean Flow	21	16	9	8	13	88	28	27	23	15	25	31	25
Observed Mean Flow	21	19	13	16	17	65	35	25	24	14	22	32	25
Computed Volume, (cm)	2.80	2.22	1.17	1.03	1.75	11.64	3.80	3.60	3.19	2.03	3.30	4.26	40.85
Observed Volume, (cm)	2.80	2.63	1.72	2.07	2.33	8.63	4.79	3.28	3.33	1.84	2.93	4.39	40.80

	1984 Nov	Dec	Jan	Feb	Mar	Apr	1985 May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	83	61	15	11	54	349	227	62	30	29	34	24	349
Observed Maximum Flow	97	62	38	18	32	326	127	31	19	19	16	25	326
Day Computed Max Occurred	4	2	1	1	31	26	1	3	1	22	6	16	Apr26
Day Observed Max Occurred	2	1	1	1	31	25	1	1	1	19	5	13	Apr25
Computed Mean Flow	46	31	12	11	18	118	82	42	20	21	21	20	37
Observed Mean Flow	54	47	26	16	17	109	64	24	15	15	12	21	35
Computed Volume, (cm)	6.13	4.20	1.63	1.33	2.51	15.66	11.19	5.59	2.70	2.81	2.75	2.70	59.26
Observed Volume, (cm)	7.16	6.39	3.49	1.97	2.36	14.41	8.73	3.17	2.08	1.99	1.64	2.87	56.30

	1985 Nov	Dec	Jan	Feb	Mar	Apr	1986 May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	40	22	9	8	15	137	52	44	30	27	35	29	137
Observed Maximum Flow	51	19	14	12	36	103	51	30	39	36	32	46	103
Day Computed Max Occurred	23	1	1	1	31	20	1	17	20	1	15	18	Apr20
Day Observed Max Occurred	21	3	19	1	31	9	1	2	27	11	12	16	Apr 9
Computed Mean Flow	27	14	8	8	8	84	32	29	20	18	23	17	24
Observed Mean Flow	34	15	13	10	12	79	37	22	21	25	24	30	27
Computed Volume, (cm)	3.51	1.89	1.13	.96	1.11	11.11	4.33	3.81	2.76	2.52	3.00	2.35	38.55
Observed Volume, (cm)	4.51	2.04	1.75	1.21	1.60	10.38	5.10	2.97	2.85	3.40	3.16	4.12	43.14

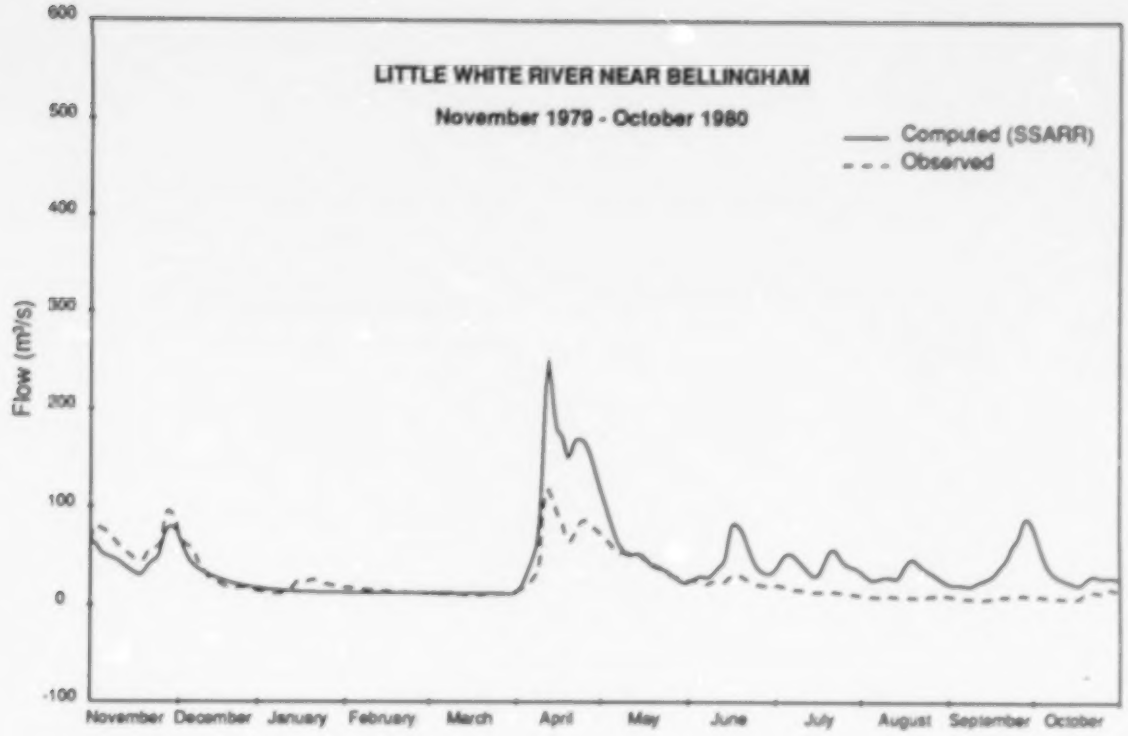
	1986 Nov	Dec	Jan	Feb	Mar	Apr	1987 May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	13	9	6	5	76	71	18	15	17	12	12	16	76
Observed Maximum Flow	24	20	13	10	39	45	26	22	12	9	5	8	45
Day Computed Max Occurred	12	1	1	1	30	1	24	16	16	22	24	30	Mar30
Day Observed Max Occurred	1	4	6	1	31	15	23	1	13	4	1	28	Apr15
Computed Mean Flow	11	7	5	5	19	30	13	11	12	10	10	11	12
Observed Mean Flow	20	14	11	9	14	36	21	14	10	6	3	6	14
Computed Volume, (cm)	1.40	.94	.69	.58	2.63	3.93	1.83	1.51	1.64	1.34	1.34	1.55	19.42
Observed Volume, (cm)	2.62	1.91	1.50	1.16	1.92	4.72	2.93	1.90	1.36	.79	.42	.81	22.08

Table A2

SSARR Calibration Performance Results (cont'd)

	1987 Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	15	35	11	7	21	214	81	30	19	37	30	67	214
Observed Maximum Flow	17	25	13	10	55	244	61	28	12	24	14	71	244
Day Computed Max Occurred	1	15	1	29	31	12	17	1	18	18	1	31	Apr12
Day Observed Max Occurred	30	12	1	1	31	8	1	1	27	16	1	28	Apr 8
Computed Mean Flow	12	18	8	6	8	129	54	17	14	25	20	41	29
Observed Mean Flow	11	17	11	10	16	120	48	17	9	14	11	40	27
Computed Volume, (cm)	1.59	2.48	1.04	.82	1.16	17.12	7.32	2.23	1.95	3.39	2.68	5.55	47.38
Observed Volume, (cm)	1.44	2.30	1.44	1.22	2.16	15.81	6.50	2.20	1.23	1.90	1.39	5.50	43.14

	1988 Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Computed Maximum Flow	171	104	18	13	13	266	261	83	32	14	16	12	266
Observed Maximum Flow	175	107	26	16	40	133	119	42	22	10	7	5	175
Day Computed Max Occurred	7	1	1	1	1	30	1	19	1	8	13	21	Apr30
Day Observed Max Occurred	7	1	8	1	31	28	1	19	1	4	1	6	Nov 7
Computed Mean Flow	104	41	15	13	13	102	111	52	18	13	12	11	42
Observed Mean Flow	106	43	21	13	15	72	64	31	14	8	6	4	33
Computed Volume, (cm)	13.70	5.54	1.99	1.62	1.74	13.45	15.18	6.91	2.40	1.78	1.63	1.47	67.46
Observed Volume, (cm)	13.99	5.94	2.86	1.65	2.02	9.45	8.70	4.15	1.86	1.13	.78	.60	53.18



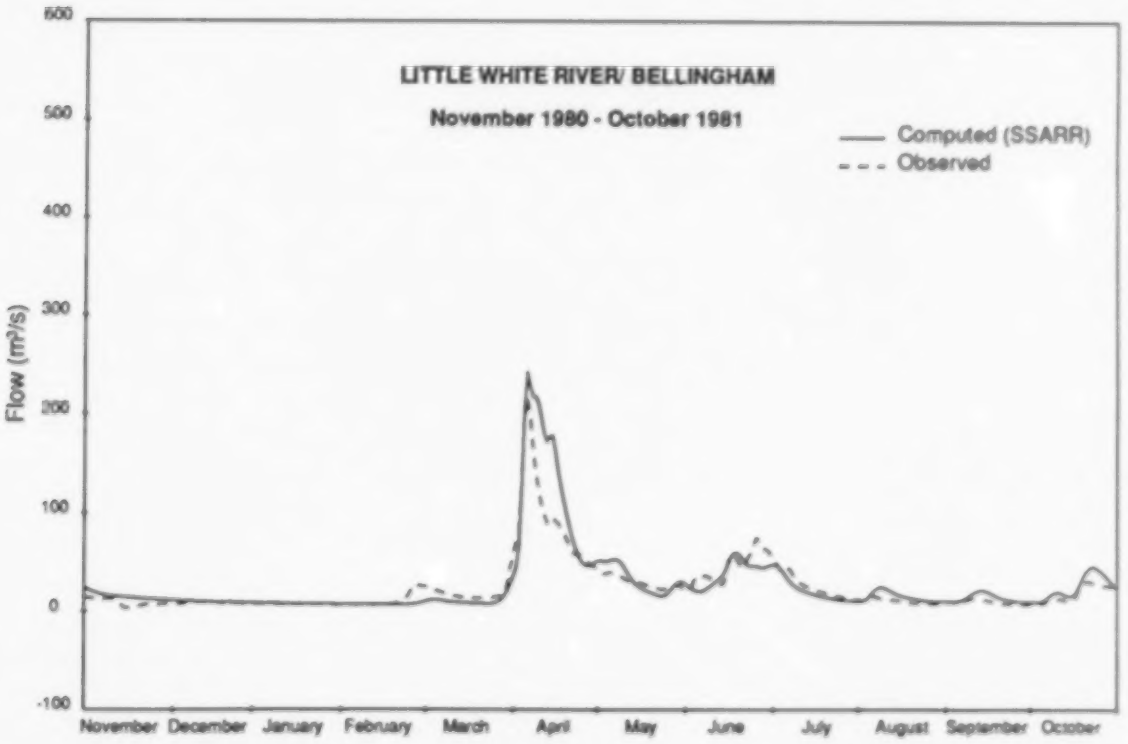
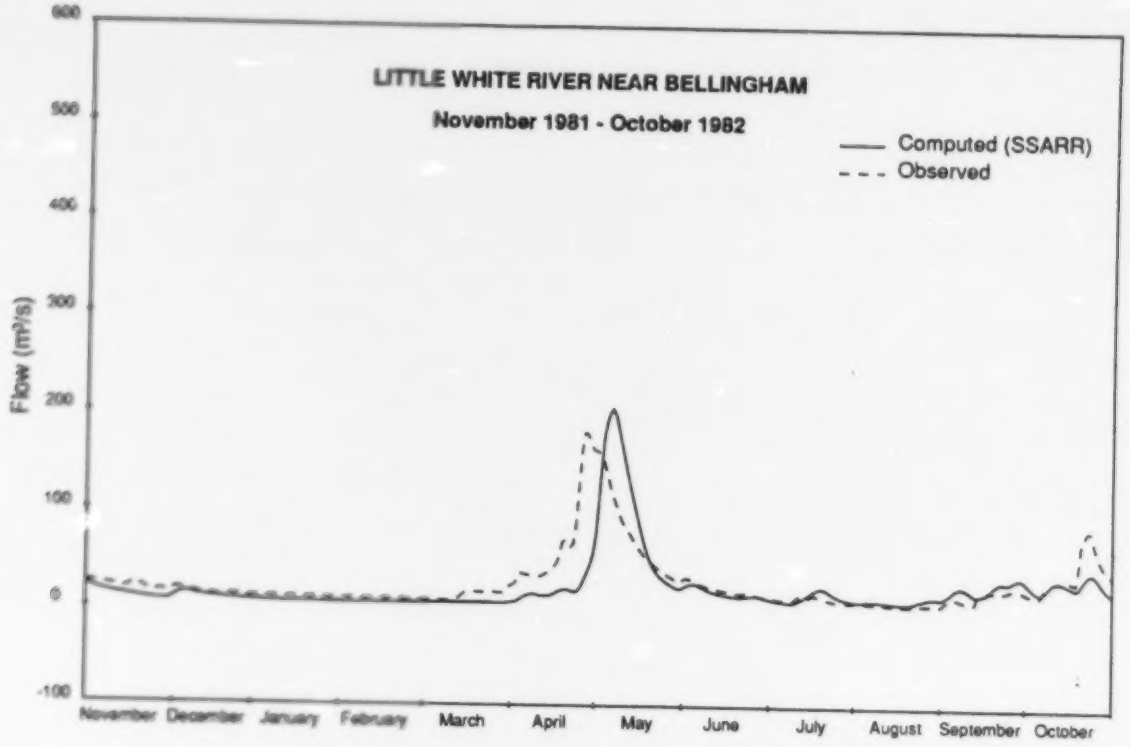


Figure A.1 Calibration Results (November 1979 - October 1981)



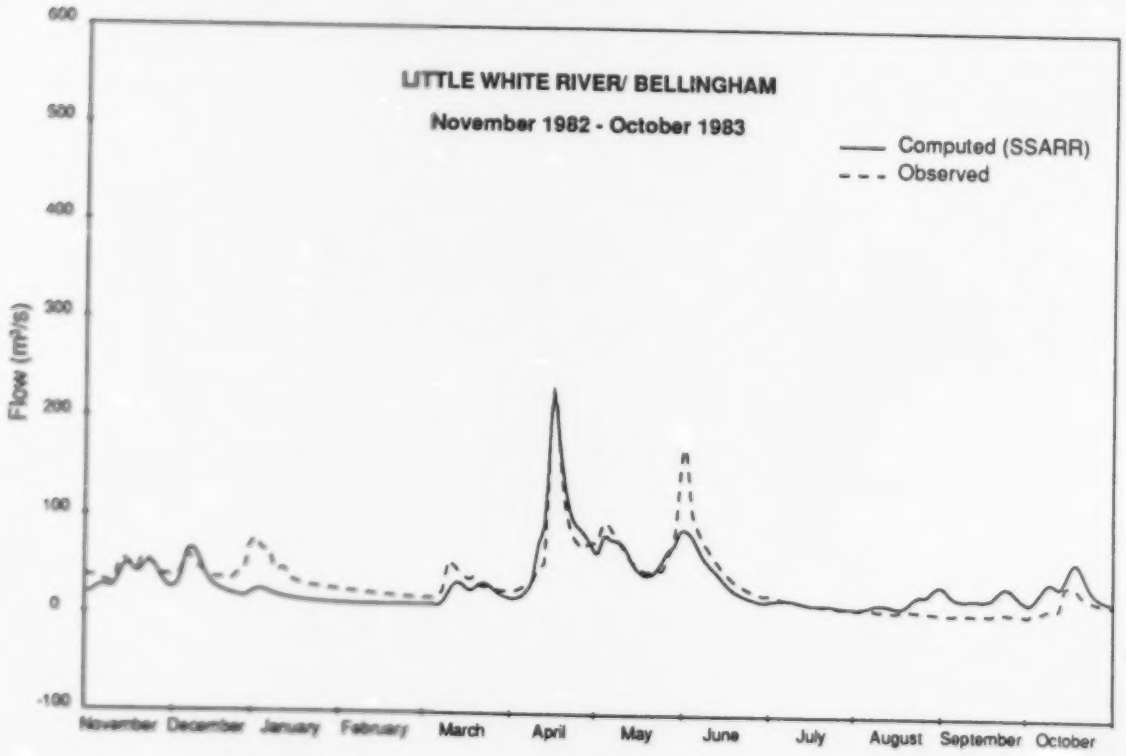
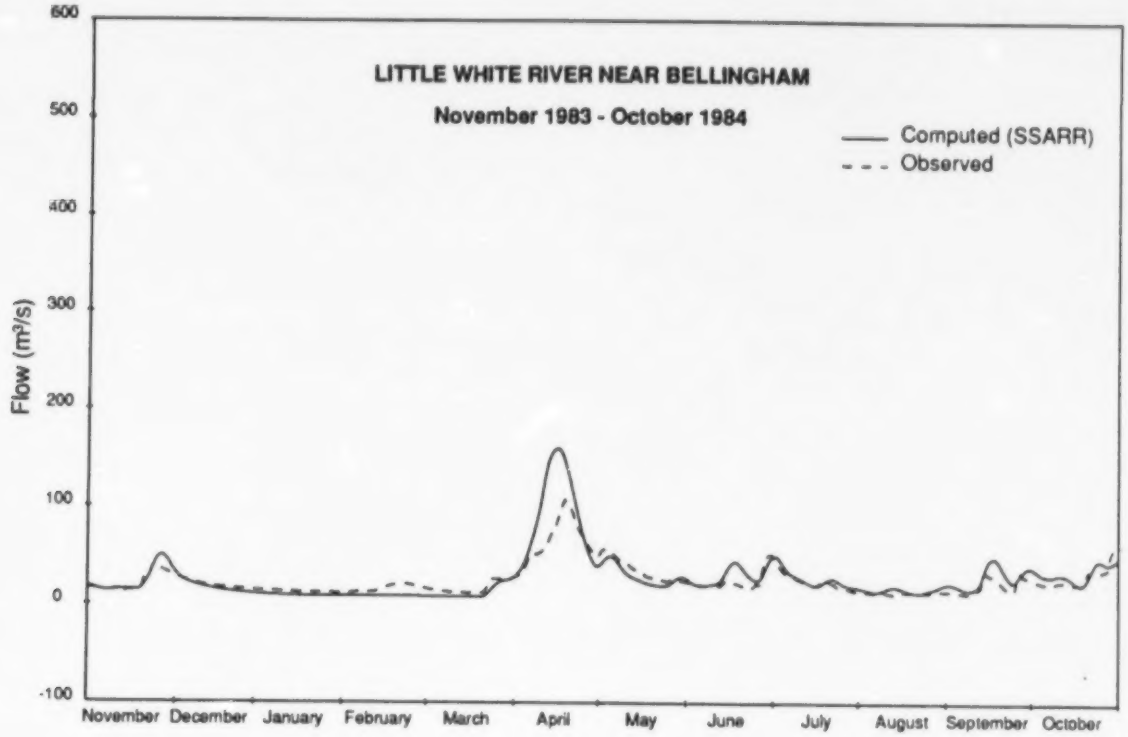


Figure A.2 Calibration Results (November 1981 - October 1983)



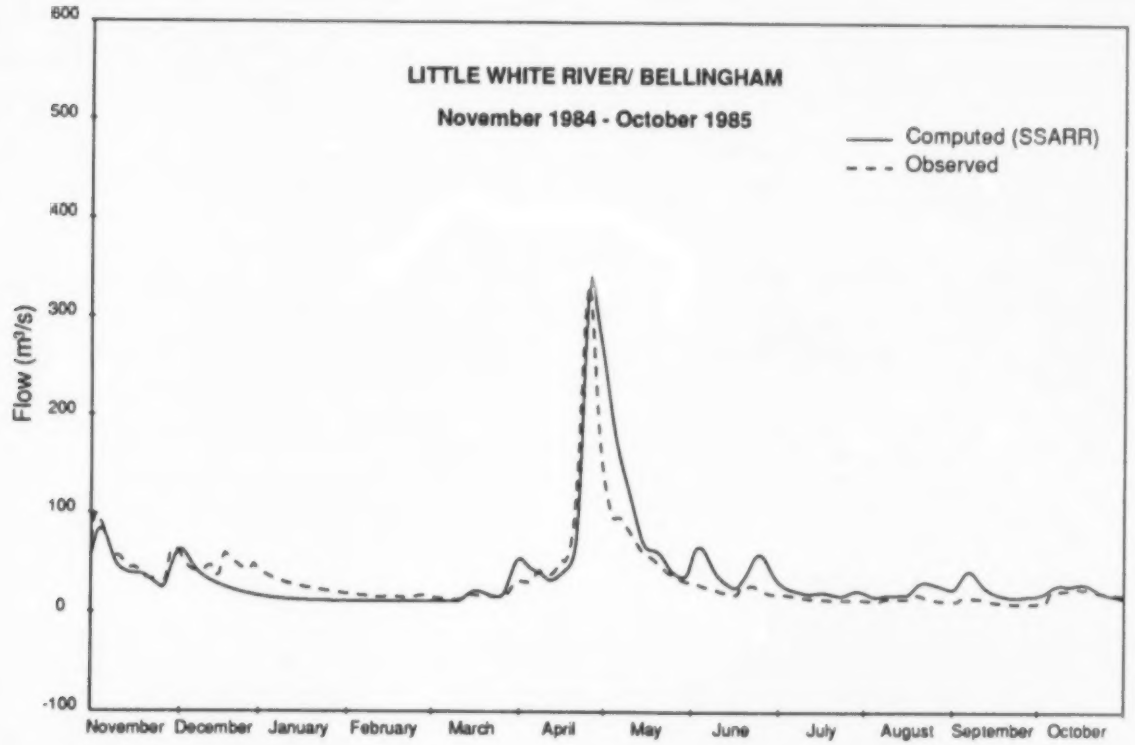
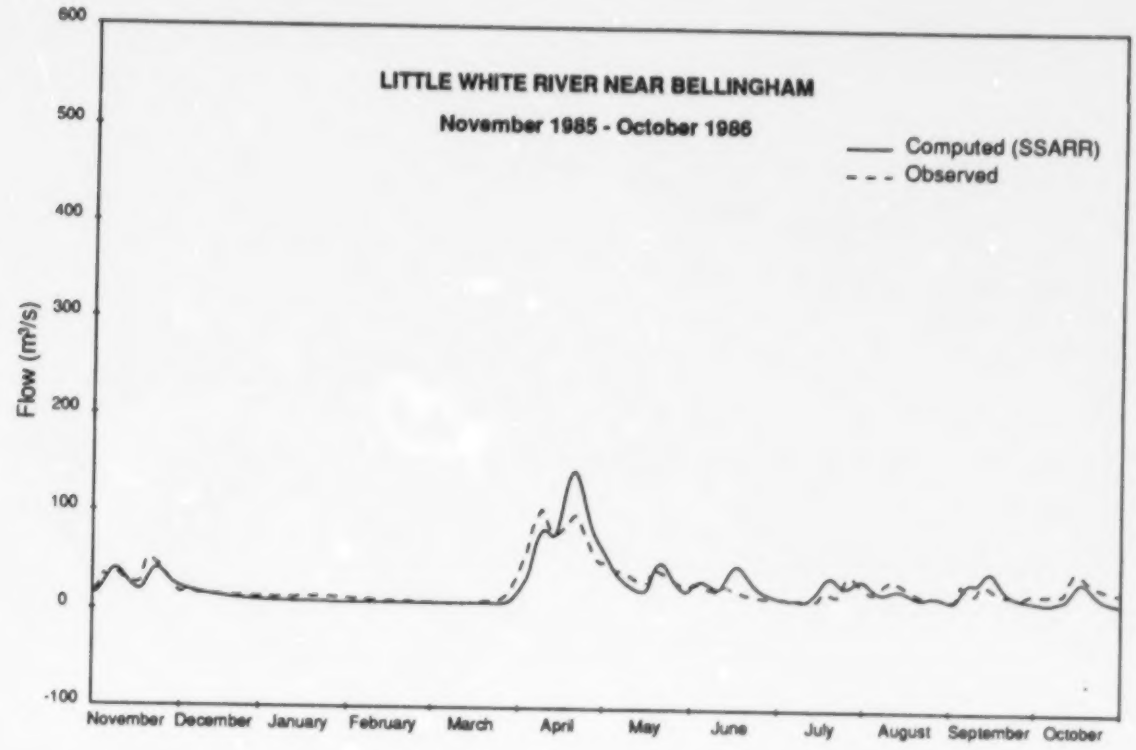


Figure A.3 Calibration Results (November 1983 - October 1985)



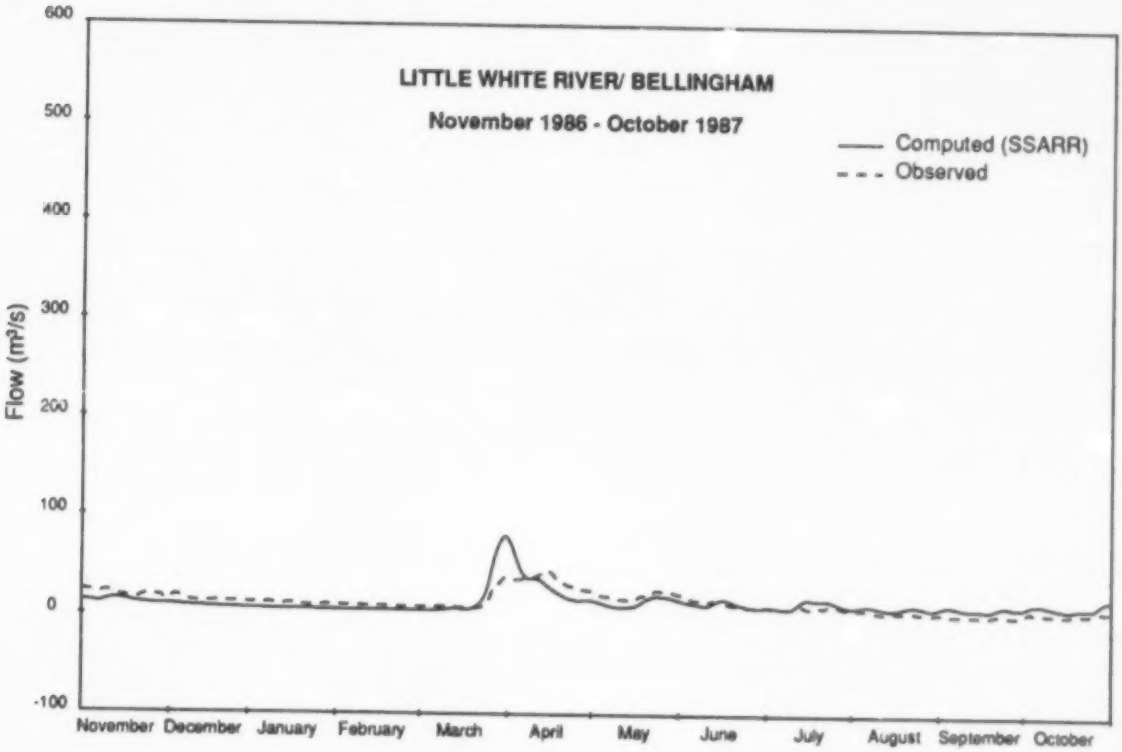
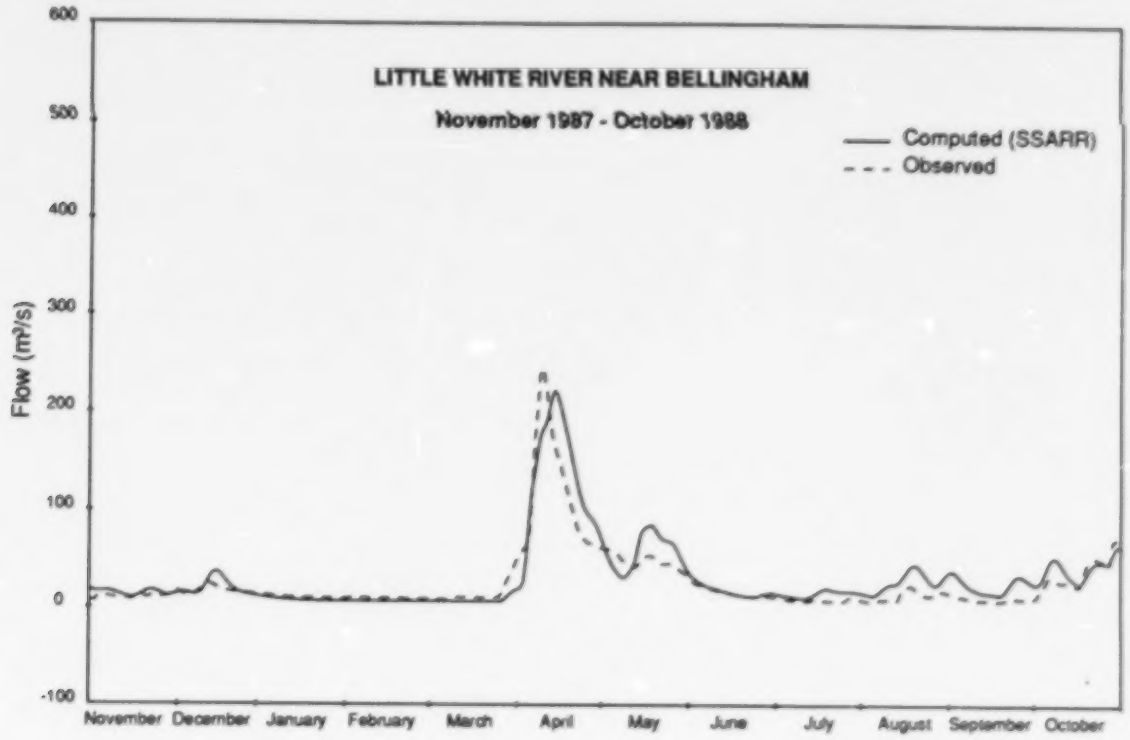


Figure A.4 Calibration Results (November 1985 - October 1987)



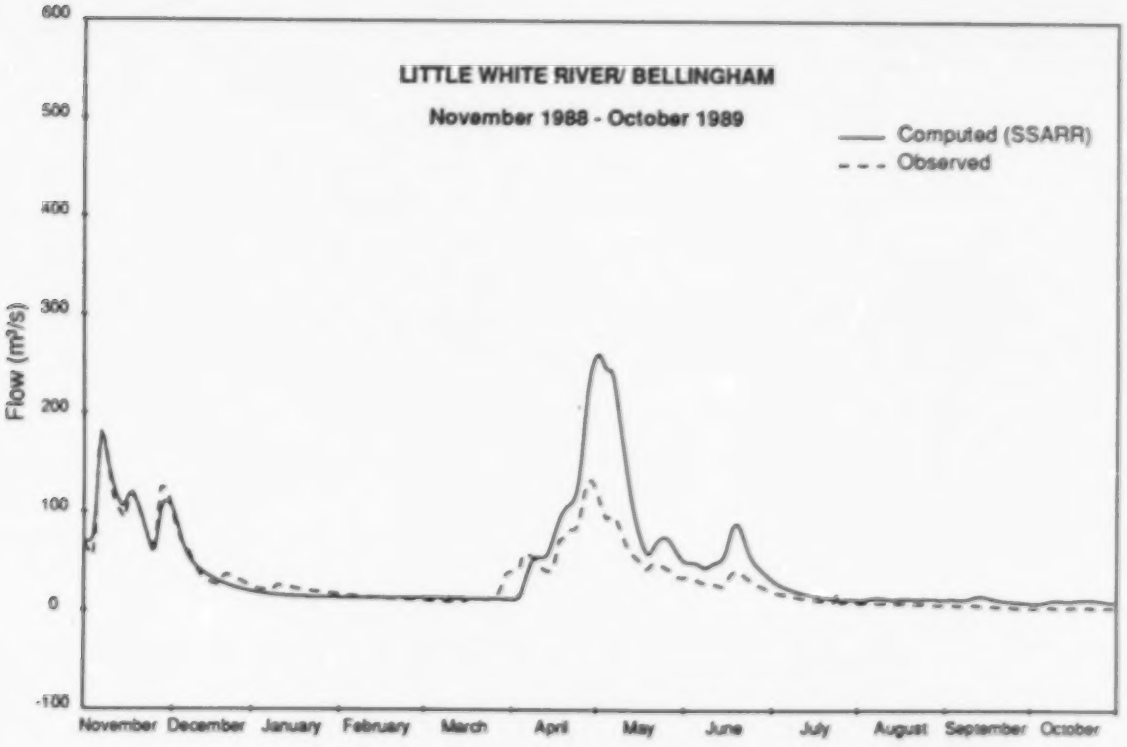


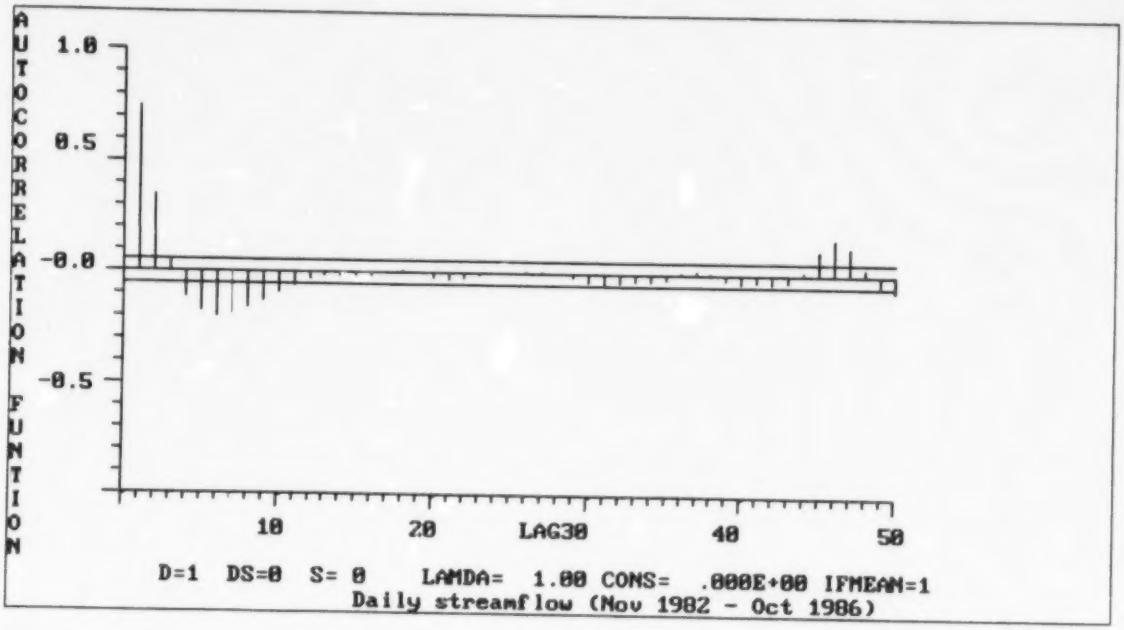
Figure A.5 Calibration Results (November 1987 - October 1989)

APPENDIX B

ARIMA Models Identification and Parameter Estimation

Figure B1. ARIMA(1,1,1) Autocorrelation Functions
Figure B2. ARIMA(1,2,2) Autocorrelation Functions

Table B1. ARIMA(1,1,1) Parameter Estimation
Table B2. ARIMA(1,2,2) Parameter Estimation



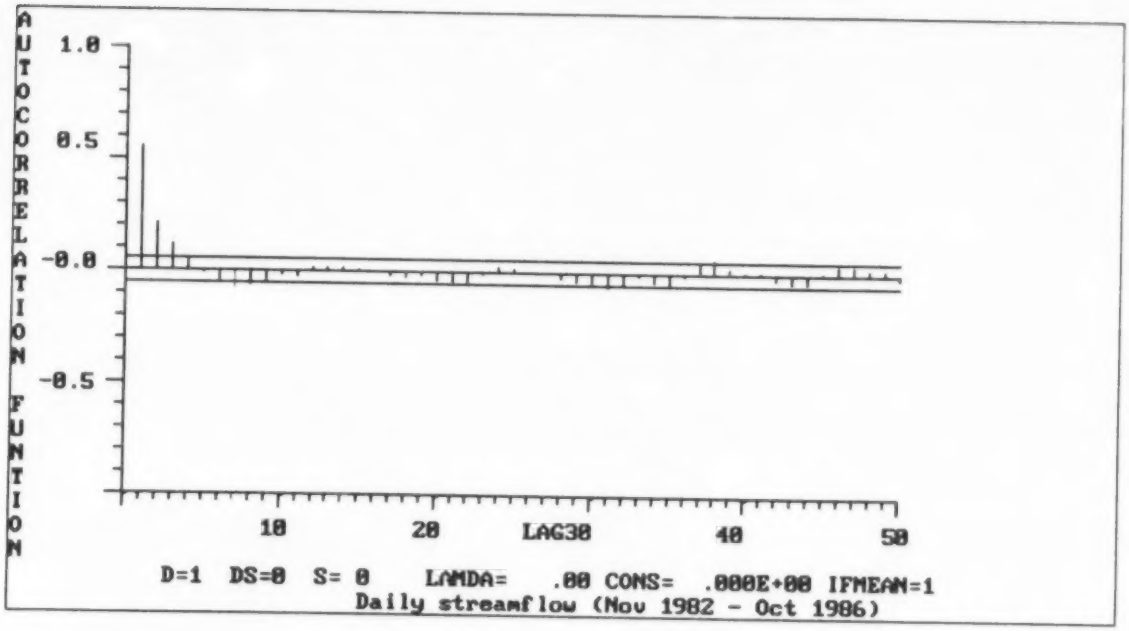
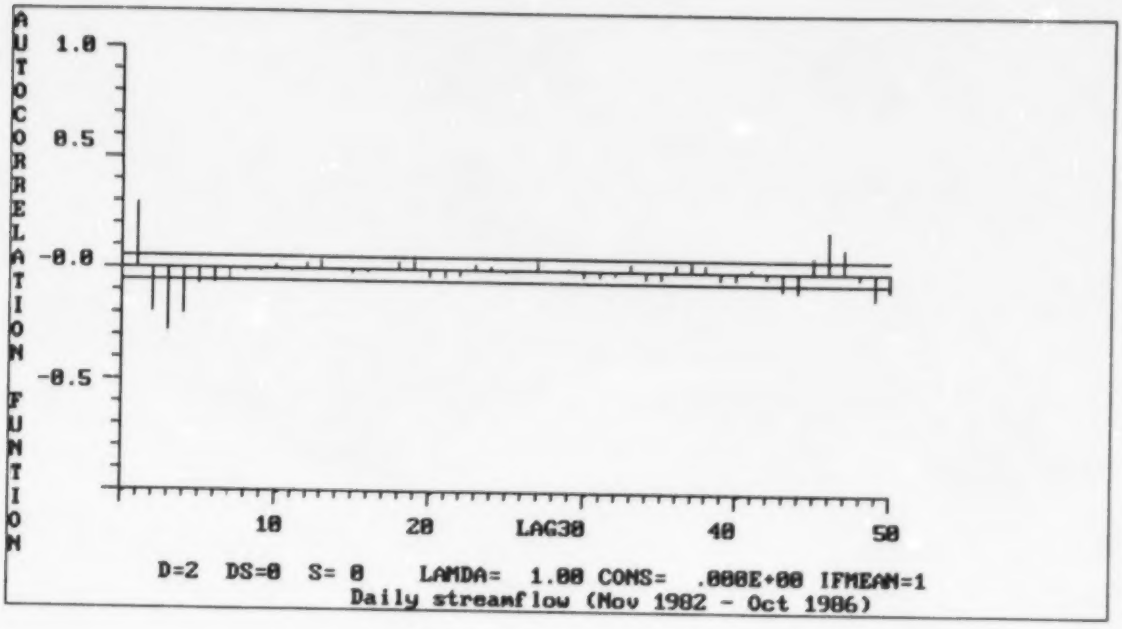


Figure B.1. ARIMA(1,1,1) Autocorrelation Functions



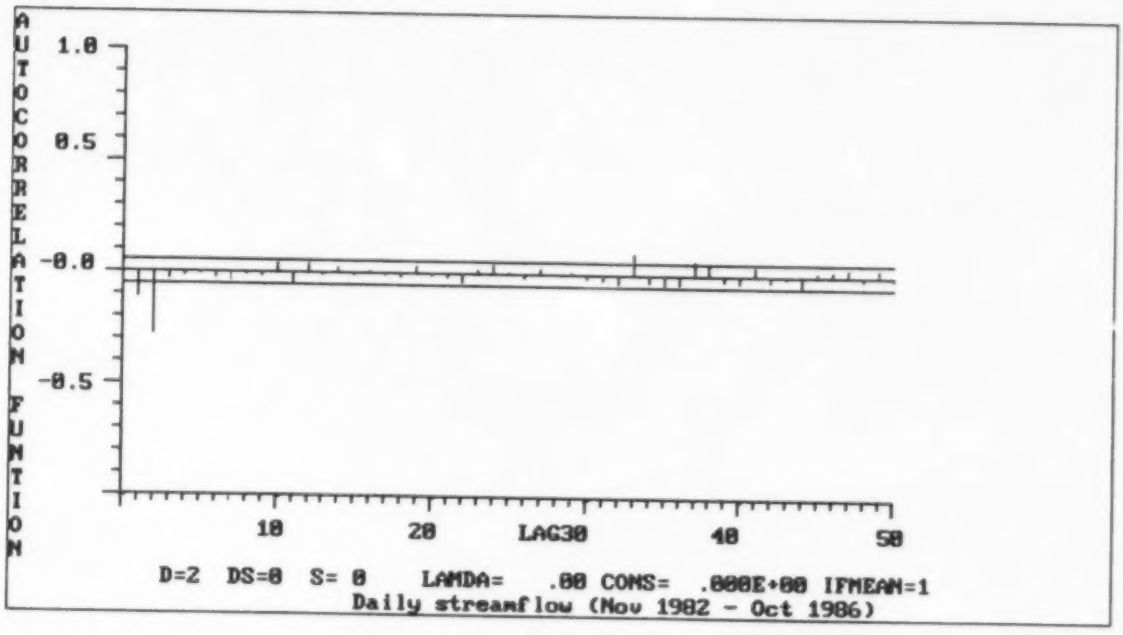


Figure B.2. ARIMA(1,2,2) Autocorrelation Functions

Table B1

ARIMA (1,1,1) Parameter Estimation

Daily streamflow (Nov 1982 - Oct 1986)

SARIMA(1, 1, 1)(0, 0, 0) 0
LENGTH OF THE INPUT TIME SERIES = 1461
LENGTH OF DIFFERENCED TIME SERIES = 1460

MODIFIED SUM OF SQUARES ESTIMATION

SUM OF SQUARES	RESIDUAL VARIANCE	R-SQ
4.61041112D+03	5.47315332D-03	3.26%

AIC	BIC
1.68797555D+03	-8.54561528D+02

BOX-COX TRANSFORMATION PARAMETERS

LAMDA	SE(LAMDA)	CONS
0.0000	0.0000	0.0000000D+00

DETERMINISTIC COMPONENT

SERIES MEAN	S.E.	TREND TERM	S.E.
-2.9751810-04	3.843327D-03	-1.975005D-04	2.556368D-03

ESTIMATED BETA PARAMETERS

BETA	SE(BETA)
0.3362	0.0417
-0.3177	0.0420

CORRELATION MATRIX OF BETA

1.000
0.807 1.000

----------RESIDUAL ANALYSIS----------

SKEWNESS		KURTOSIS	
G1	S.L.	G2	S.L.
3.2979	0.000000	26.2526	0.000000

TEST FOR HETEROSCEDASTICITY DEPENDING ON THE CURRENT LEVEL

CHI	SE(CHI)
0.471271	0.055144

TEST FOR TRENDS IN THE VARIANCE OVER TIME

CHI	SE(CHI)
-0.000379	0.000088

Table B1

ARIMA (1,1,1) Parameter Estimation (cont'd)

	RESIDUAL AND SQUARED-RESIDUAL AUTOCORRELATIONS				
LAG	RA	SE	QA	RAA	QAA
1	-0.00528	0.00280	0.04	0.18948	52.53
2	-0.00165	0.00285	0.04	0.01348	52.79
3	0.05442	0.02602	4.38	-0.00110	52.79
4	0.00929	0.02602	4.51	0.01101	52.97
5	-0.00275	0.02617	4.52	0.00392	52.99
6	-0.02503	0.02617	5.44	0.00161	53.00
7	-0.04598	0.02617	8.55	-0.00857	53.11
8	-0.01814	0.02617	9.03	-0.00053	53.11
9	-0.03591	0.02617	10.93	-0.00970	53.24
10	0.02929	0.02617	12.19	-0.01314	53.50
11	-0.05069	0.02617	15.98	0.05291	57.62
12	0.04034	0.02617	18.38	0.14669	89.34
13	-0.01328	0.02617	18.64	0.03973	91.67
14	0.02520	0.02617	19.57	-0.01096	91.85
15	-0.00866	0.02617	19.68	-0.01101	92.03
16	0.00759	0.02617	19.77	-0.01250	92.26
17	-0.00714	0.02617	19.84	-0.01960	92.83
18	-0.02140	0.02617	20.52	-0.01897	93.36
19	0.01404	0.02617	20.81	-0.00928	93.49
20	-0.02598	0.02617	21.81	-0.01901	94.02
21	-0.01497	0.02617	22.15	-0.01962	94.59
22	-0.04125	0.02617	24.67	-0.01406	94.89
23	0.00679	0.02617	24.74	-0.00456	94.92
24	0.02521	0.02617	25.68	0.01831	95.42
25	0.01132	0.02617	25.88	0.02260	96.18
26	-0.01648	0.02617	26.28	0.00722	96.26
27	0.01644	0.02617	26.68	-0.00040	96.26
28	-0.01735	0.02617	27.13	-0.01422	96.56
29	-0.00480	0.02617	27.17	0.00168	96.56
30	-0.03324	0.02617	28.81	0.00043	96.56
31	-0.01872	0.02617	29.34	0.01284	96.81
32	-0.05875	0.02617	34.50	0.01274	97.05
33	0.06388	0.02617	40.60	0.03821	99.23
34	-0.04791	0.02617	44.04	-0.00016	99.23
35	-0.02341	0.02617	44.86	-0.01024	99.39
36	-0.02920	0.02617	46.14	0.05810	104.45
37	0.05209	0.02617	50.21	0.04010	106.86
38	0.04724	0.02617	53.56	0.05950	112.18
39	-0.00201	0.02617	53.56	0.03367	113.88
40	-0.01969	0.02617	54.15	-0.00089	113.88
41	0.03774	0.02617	56.29	0.01759	114.35
42	-0.03258	0.02617	57.89	-0.00109	114.35
43	-0.00078	0.02617	57.89	-0.00131	114.35

Table B1

ARIMA (1,1,1) Parameter Estimation (cont'd)

RESIDUAL AND SQUARED-RESIDUAL AUTOCORRELATIONS

LAG	RA	SE	QA	RAA	QAA
44	-0.05359	0.02617	62.22	0.00146	114.36
45	0.02165	0.02617	62.92	0.03308	116.01
46	0.01485	0.02617	63.26	0.02084	116.66
47	0.03595	0.02617	65.21	0.01478	116.99
48	-0.01373	0.02617	65.49	0.00346	117.01
49	0.03209	0.02617	67.05	0.02350	117.85
50	-0.01113	0.02617	67.24	0.00771	117.94
51	-0.02784	0.02617	68.41	-0.00919	118.06
52	-0.02110	0.02617	69.09	-0.01810	118.56
53	-0.00536	0.02617	69.13	-0.01689	118.99
54	-0.03446	0.02617	70.93	-0.01514	119.34
55	-0.00437	0.02617	70.96	-0.01595	119.73
56	-0.02649	0.02617	72.03	-0.00589	119.78
57	0.01465	0.02617	72.36	-0.00555	119.83
58	0.00343	0.02617	72.37	-0.01319	120.09
59	0.01563	0.02617	72.75	-0.01464	120.42
60	0.00450	0.02617	72.78	-0.01374	120.71

Q(60) = 72.78 ON 58 DF IS NOT SIGNIFICANT AT THE 5 PERCENT LEVEL

Q(60) = 120.71 ON 60 DF, S.L. = 1.848E-06

Table B2

ARIMA (1,2,2) Parameter Estimation

Daily streamflow (Nov 1982 - Oct 1986)
SARIMA(1, 2, 2)(0, 0, 0) 0
LENGTH OF THE INPUT TIME SERIES = 1461
LENGTH OF DIFFERENCED TIME SERIES = 1459

MODIFIED SUM OF SQUARES ESTIMATION

SUM OF SQUARES	RESIDUAL VARIANCE	R-SQ
4.631594430+03	5.485183640-03	2.42%

AIC	BIC
1.697674020+03	-8.620541990+02

BOX-COX TRANSFORMATION PARAMETERS

LAMDA	SE(LAMDA)	CONS
0.0000	0.0000	0.0000000+00

DETERMINISTIC COMPONENT

SERIES		TREND	
MEAN	S.E.	TERM	S.E.
2.718578D-06	5.522598D-06	1.799506D-06	3.664605D-06

ESTIMATED BETA PARAMETERS

BETA	SE(BETA)
0.3381	0.0418
0.6819	0.0421
0.3162	0.0419

CORRELATION MATRIX OF BETA

1.000
0.807 1.000
-0.806 -0.999 1.000

TEST FOR UNIT ROOT

MA OPERATOR - SUM = 0.0019 S.D. = 0.0019

----------RESIDUAL ANALYSIS----------

SKEWNESS		KURTOSIS	
G1	S.L.	G2	S.L.
3.2880	0.000000	26.2268	0.000000

TEST FOR HETEROSCEDASTICITY DEPENDING ON THE CURRENT LEVEL

CHI	SE(CHI)
0.453139	0.055268

Table B2

ARIMA (1,2,2) Parameter Estimation (cont'd)

TEST FOR TRENDS IN THE VARIANCE OVER TIME

CHI	SE(CHI)
-0.000376	0.000088

RESIDUAL AND SQUARED-RESIDUAL AUTOCORRELATIONS

LAG	RA	SE	QA	RAA	QAA
1	-0.00606	0.00280	0.05	0.18998	52.77
2	-0.00259	0.00286	0.06	0.01361	53.04
3	0.05440	0.02600	4.40	-0.00085	53.04
4	0.00926	0.02600	4.52	0.01096	53.22
5	-0.00267	0.02614	4.53	0.00369	53.24
6	-0.02490	0.02614	5.44	0.00164	53.24
7	-0.04580	0.02614	8.52	-0.00864	53.35
8	-0.01797	0.02614	9.00	-0.00087	53.35
9	-0.03570	0.02614	10.87	-0.00980	53.49
10	0.02947	0.02614	12.15	-0.01283	53.74
11	-0.05056	0.02614	15.91	0.05314	57.89
12	0.04036	0.02614	18.31	0.14638	89.45
13	-0.01327	0.02614	18.57	0.03993	91.81
14	0.02518	0.02614	19.51	-0.01085	91.98
15	-0.00866	0.02614	19.62	-0.01110	92.16
16	0.00761	0.02614	19.70	-0.01244	92.39
17	-0.00710	0.02614	19.78	-0.01966	92.96
18	-0.02133	0.02614	20.45	-0.01887	93.49
19	0.01419	0.02614	20.75	-0.00932	93.62
20	-0.02589	0.02614	21.74	-0.01908	94.16
21	-0.01493	0.02614	22.07	-0.01970	94.73
22	-0.04120	0.02614	24.59	-0.01421	95.03
23	0.00683	0.02614	24.66	-0.00422	95.06
24	0.02530	0.02614	25.61	0.01863	95.57
25	0.01136	0.02614	25.80	0.02220	96.31
26	-0.01641	0.02615	26.20	0.00712	96.38
27	0.01656	0.02615	26.61	-0.00032	96.38
28	-0.01720	0.02615	27.05	-0.01411	96.68
29	-0.00466	0.02615	27.08	0.00144	96.68
30	-0.03305	0.02615	28.71	0.00019	96.68
31	-0.01858	0.02615	29.23	0.01276	96.92
32	-0.05860	0.02615	34.36	0.01247	97.16
33	0.06408	0.02615	40.50	0.03823	99.34
34	-0.04772	0.02615	43.90	-0.00039	99.34
35	-0.02340	0.02615	44.72	-0.01010	99.49
36	-0.02921	0.02615	46.00	0.05854	104.63
37	0.05212	0.02615	50.07	0.04012	107.04
38	0.04729	0.02615	53.43	0.06001	112.44

Table B2

ARIMA (1,2,2) Parameter Estimation (cont'd)

RESIDUAL AND SQUARED-RESIDUAL AUTOCORRELATIONS

LAG	RA	SE	QA	RAA	QAA
39	-0.00205	0.02615	53.43	0.03388	114.16
40	-0.01967	0.02615	54.01	-0.00071	114.17
41	0.03785	0.02615	56.17	0.01760	114.63
42	-0.03246	0.02615	57.75	-0.00102	114.63
43	-0.00069	0.02615	57.75	-0.00118	114.63
44	-0.05350	0.02615	62.06	0.00141	114.64
45	0.02173	0.02615	62.78	0.03287	116.27
46	0.01497	0.02615	63.11	0.02081	116.92
47	0.03601	0.02615	65.07	0.01508	117.26
48	-0.01367	0.02615	65.35	0.00346	117.28
49	0.03218	0.02615	66.92	0.02358	118.12
50	-0.01100	0.02615	67.10	0.00759	118.21
51	-0.02772	0.02615	68.27	-0.00929	118.34
52	-0.02090	0.02615	68.93	-0.01807	118.83
53	-0.00516	0.02615	68.97	-0.01684	119.26
54	-0.03431	0.02615	70.75	-0.01535	119.62
55	-0.00425	0.02615	70.78	-0.01593	120.01
56	-0.02641	0.02615	71.84	-0.00606	120.06
57	0.01475	0.02615	72.17	-0.00551	120.11
58	0.00345	0.02615	72.19	-0.01327	120.38
59	0.01562	0.02615	72.56	-0.01466	120.70
60	0.00452	0.02615	72.59	-0.01379	120.99

Q(60) = 72.59 ON 57 DF IS NOT SIGNIFICANT AT THE 5 PERCENT LEVEL

Q(60) = 120.99 ON 60 DF, S.L. = 1.669E-06